Stay-In-Place Formwork

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CENTRAL BUILDING RESEARCH INSTITUTE, ROORKEE
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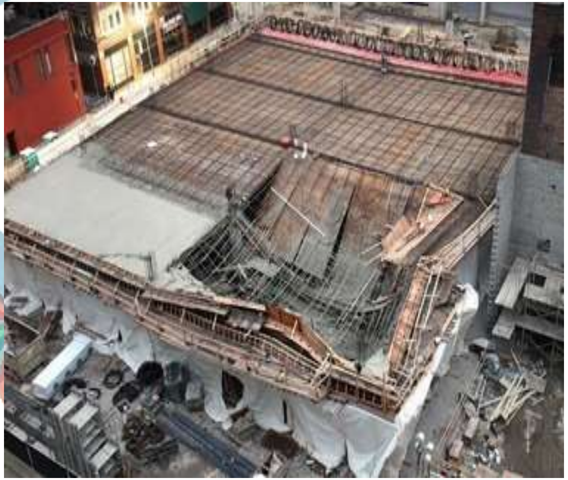
Formwork in Construction

Importance of Formwork






Limitations

1. **Wood, steel sheets/plates, ply boards, Aluminum, Plastics etc… are com monly used form work materials.**

2. **Formwork costs around 40-50% of the total construction cost in RCC.**

3. **Storing and limitations in reusing increases the capital investment in con struction industry.**

4. **Formwork arrangement and its alignment consumes more time compare d to the concreting work.**

5. **Aluminum form work, steel form work, vinyl based form work, rubber and glass form works are also available. But still the capital investments are high and requires maintenance, transportation, storing unit etc..**

NEED OF STAY-IN-PLACE FORM WORK

Stay in place (SIP) form work system is an effective and advanced way of formwork system.

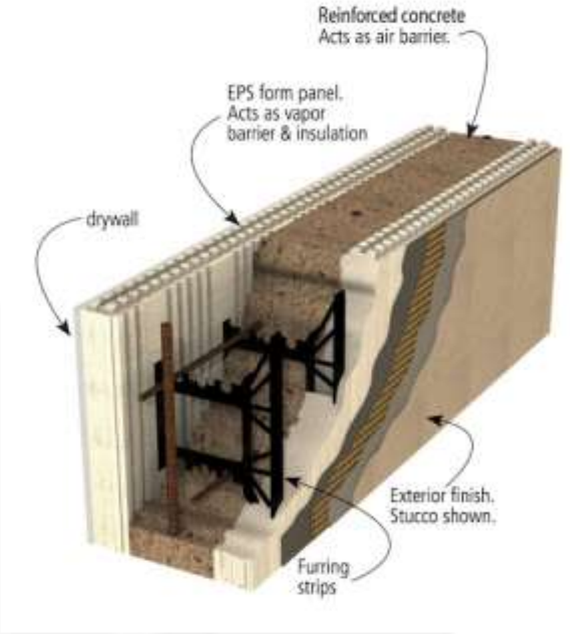
In SIP the formwork material become an integral part of the structural ele ments Advantages such as thermal comfort, external protection to resist the durability issues, additional confining pressure and reduces the construction time and offers viable economical solution.

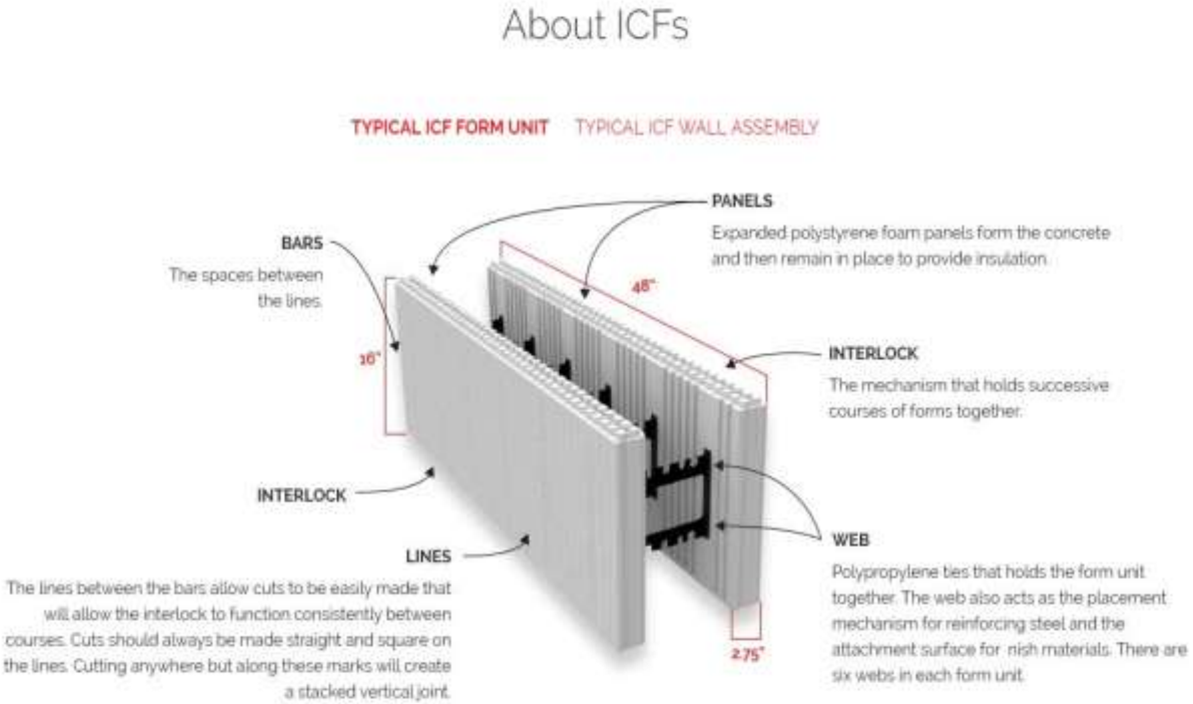
Different materials such as fibers reinforced polymers (FRP), polyvinyl (PVC), Cementitious composites, extended polystyrene (EPS), glass fiber reinforced concrete/composites (GFRP), steel composites, steel meshes etc... have been in practice.

Research Scope in SIP

Numerous researches have focused on improving the SIP system more systematically and efficiently. Problems such as the bond between the fresh concrete and the form work materials influence on the elemental behavior, failure pattern, life span etc… have been identified as issues in SIP systems and research level and practical level solutions also had been proposed.

INSULATED CONCRETE FORMS (ICF)

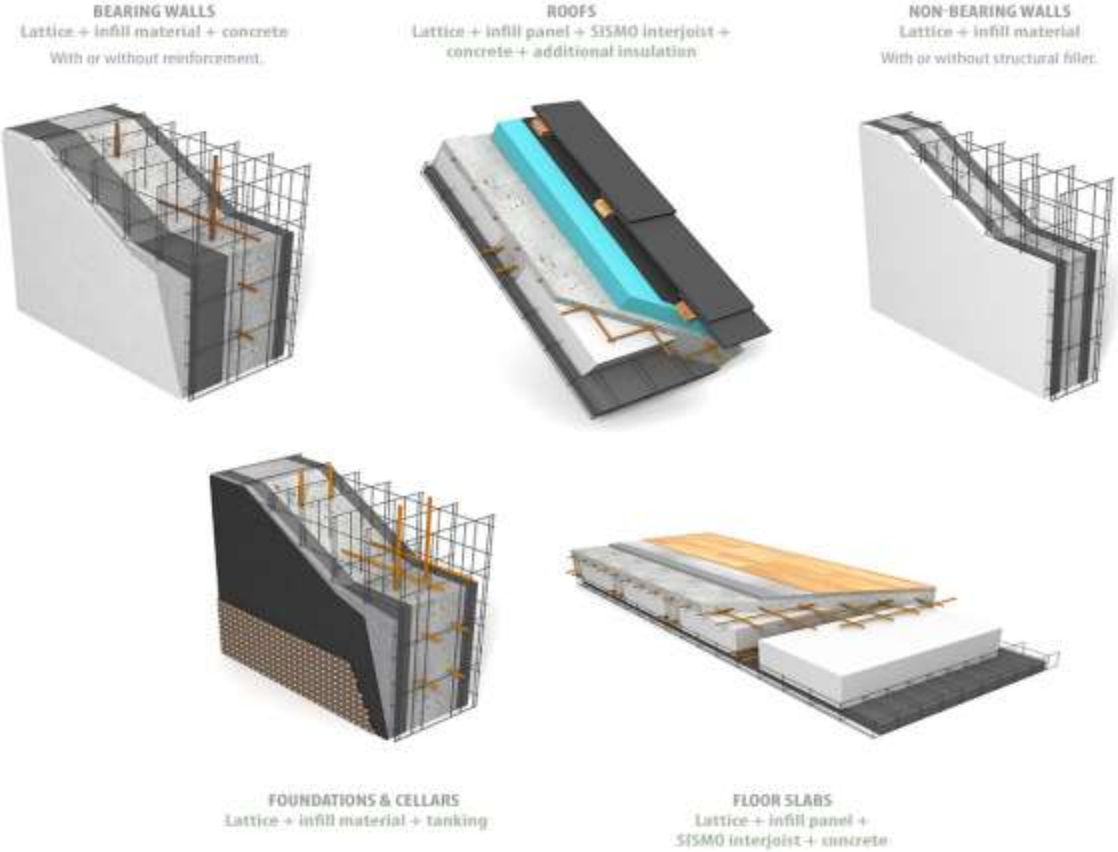




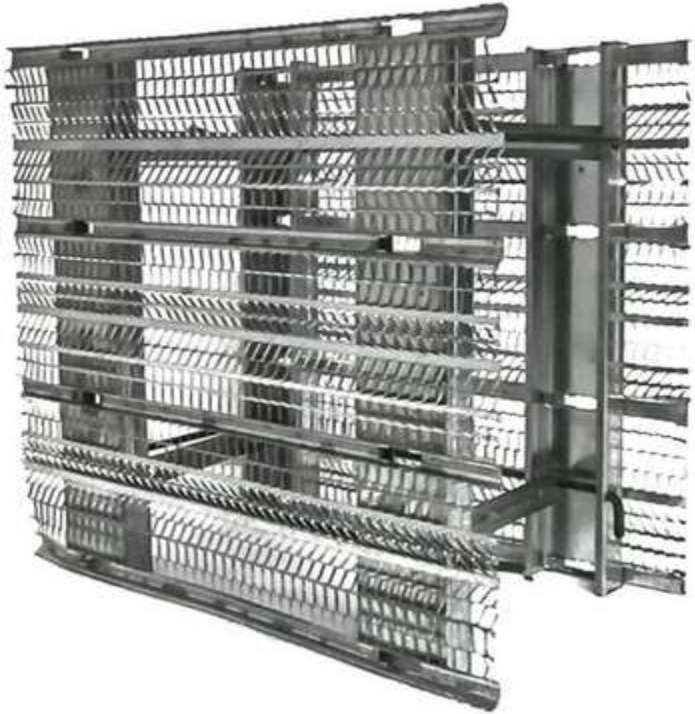
Advantages

- Offers resistance to gravity and lateral loading due to its monolith ic construction technique.
- Energy efficiency and thermal comfort
- Noise reduction
- Resistant to corrosion.
- Easy to install and time saving construction technique.
- Cost effective solution.

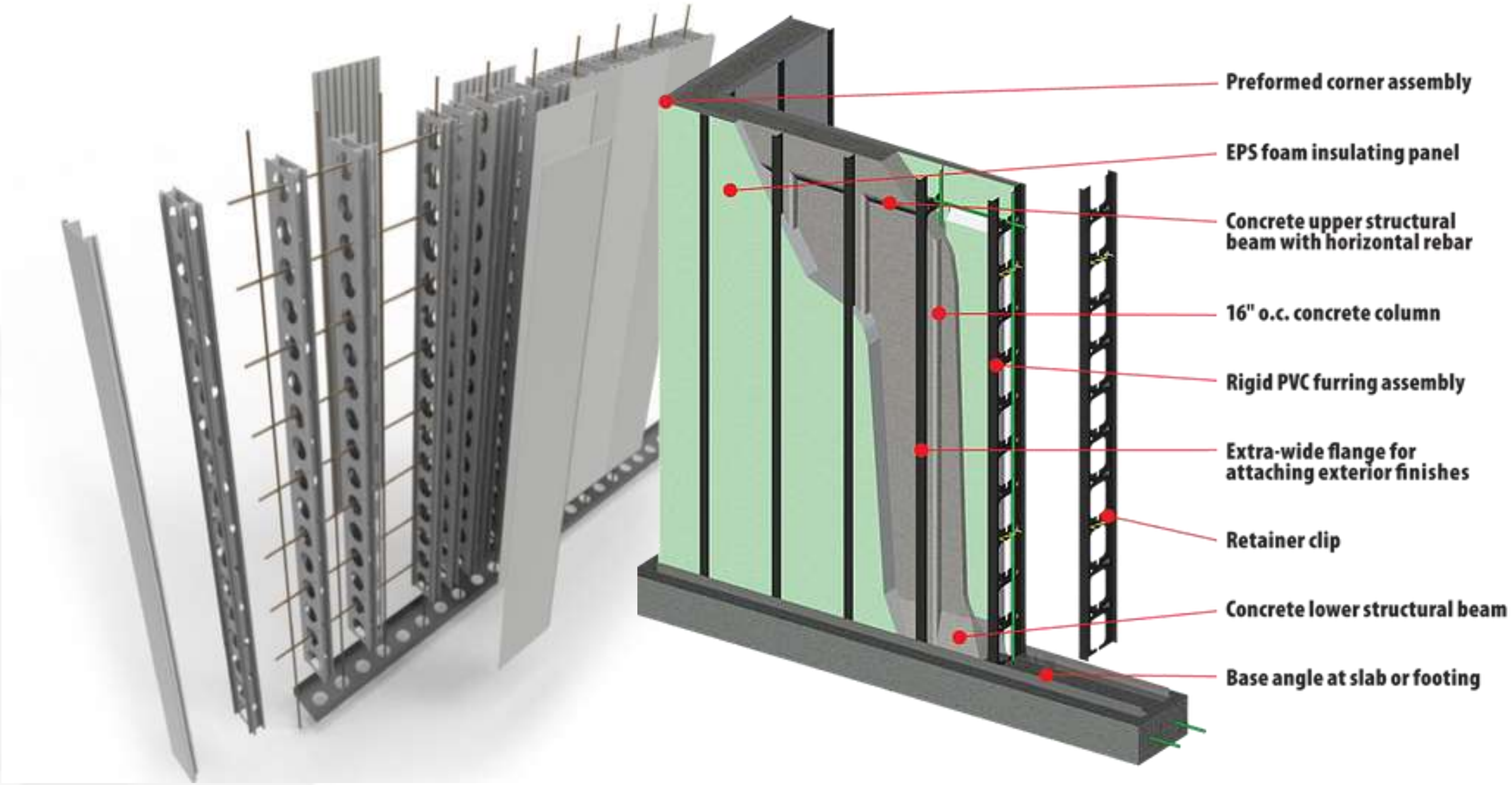
LATTICE BASED ICF SYSTEM AND ITS DIFFERENT MODULES

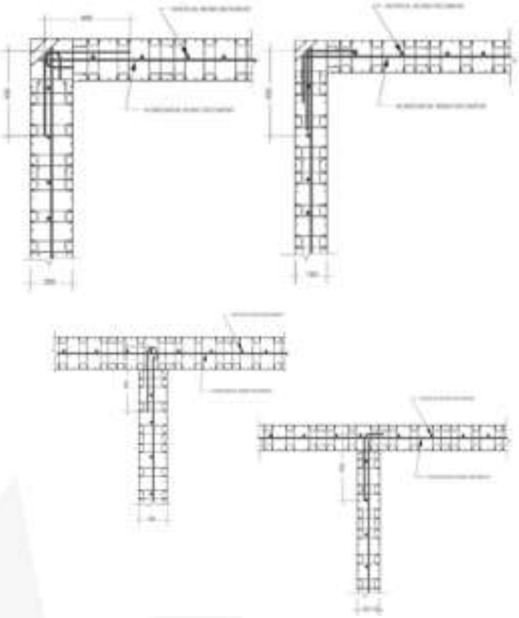


Structural SIP system

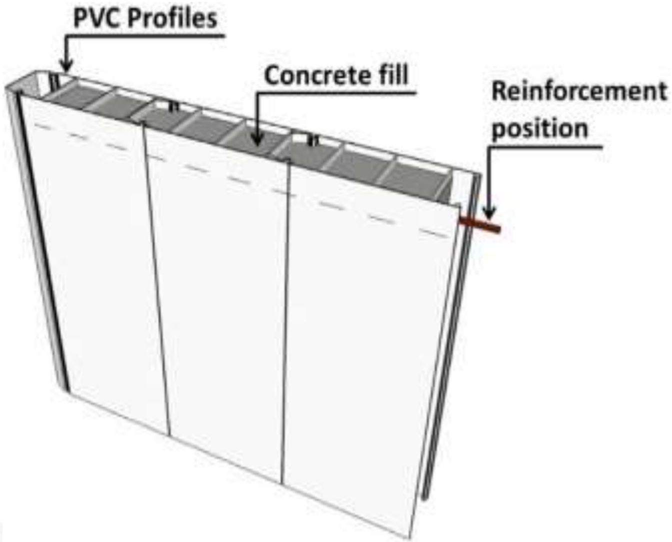


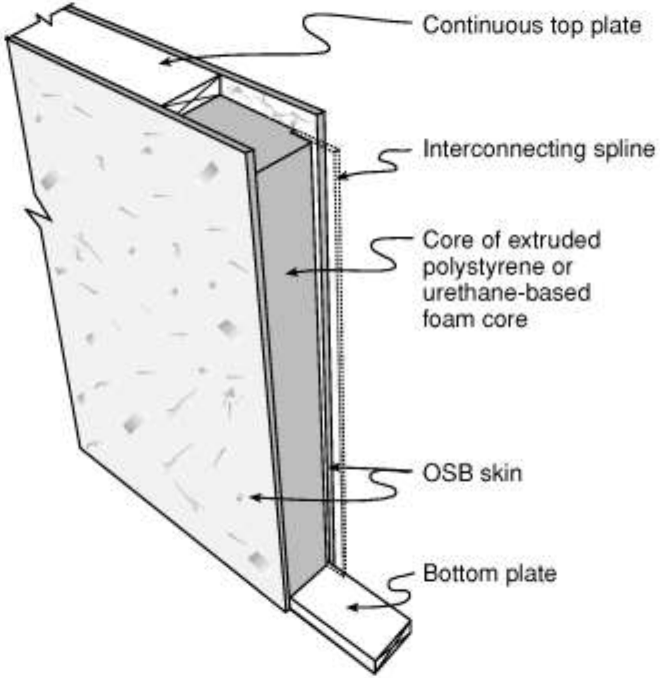
PVC Based SIP system

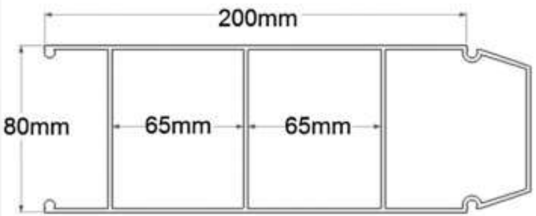


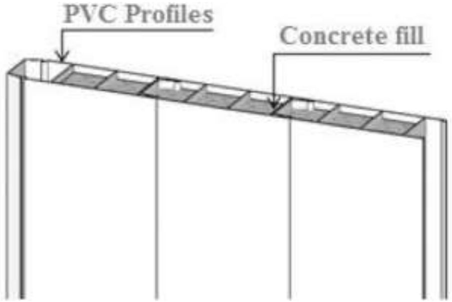


PVC Profile – Concrete Filler - SIP system

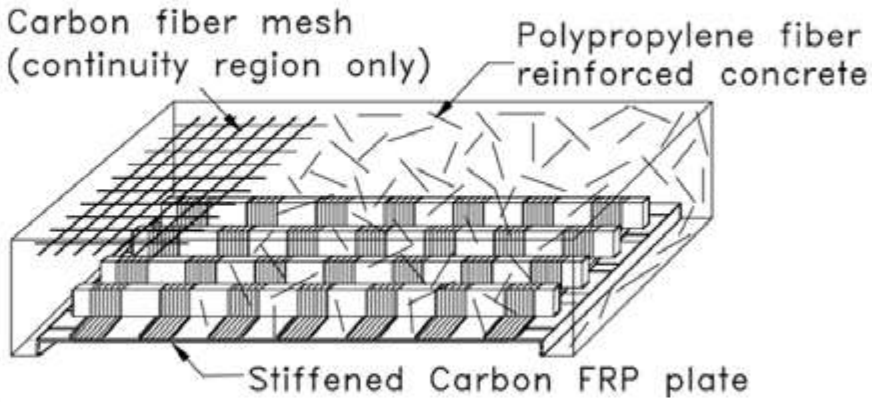


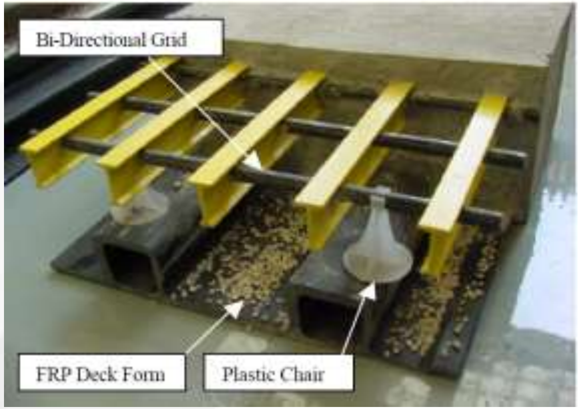


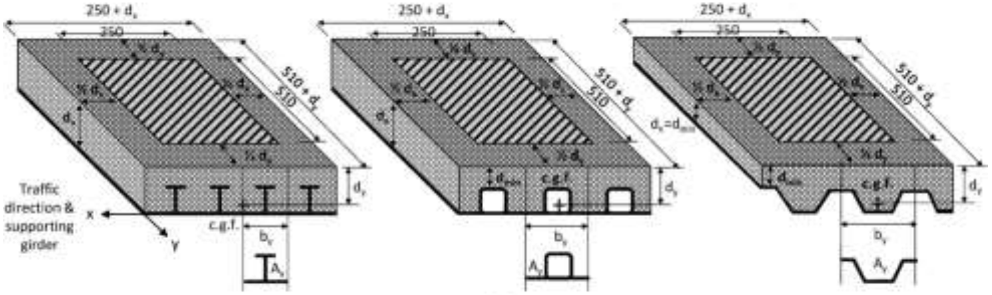


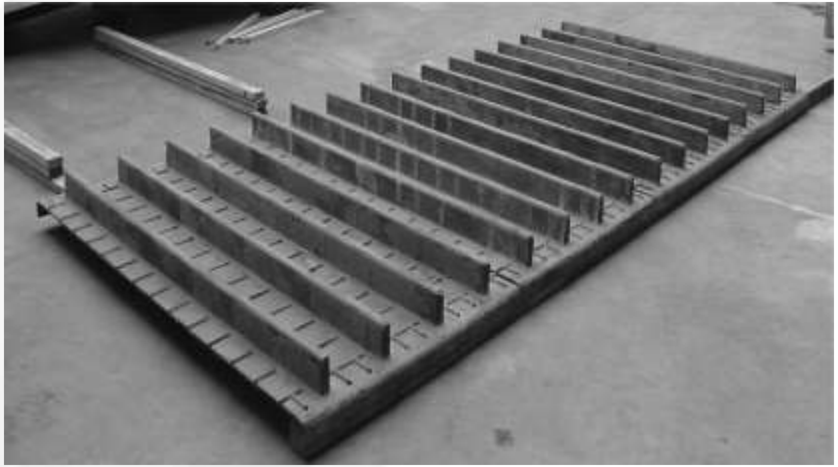


FRP BASED SIP FORM WORK SYSTEM



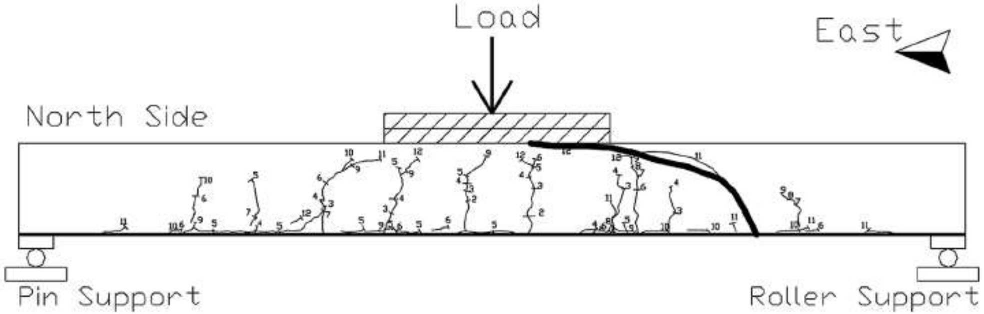


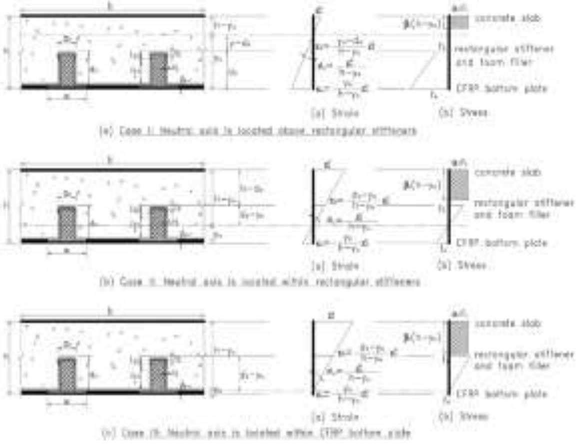

250 + d_x
250
½ d_x
510 + d_y
510
½ d_y
d_x
d_y
d_min
d_x=d_min
c.g.f.
Traffic direction & supporting girder
x
y
b_y
A_y
(a)



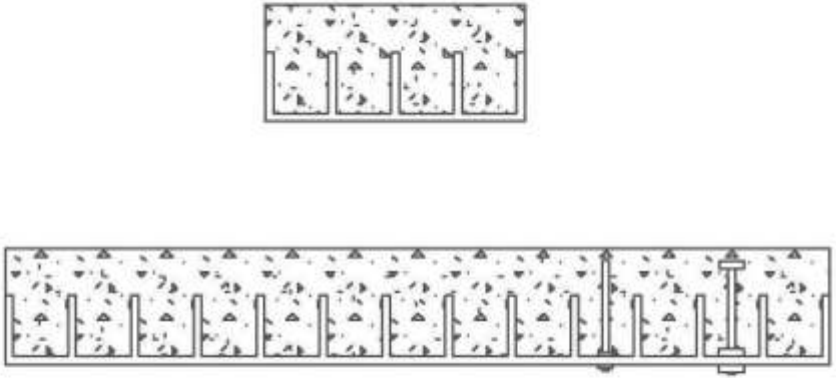

(b)

Structural Behavior of FRP SIP





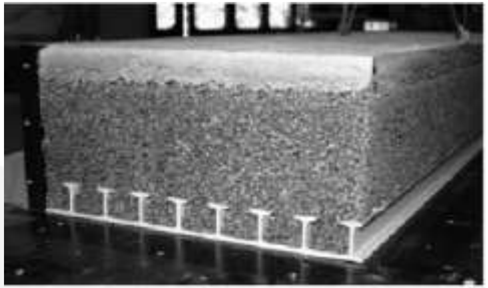
FRP panel with Sand blast coating

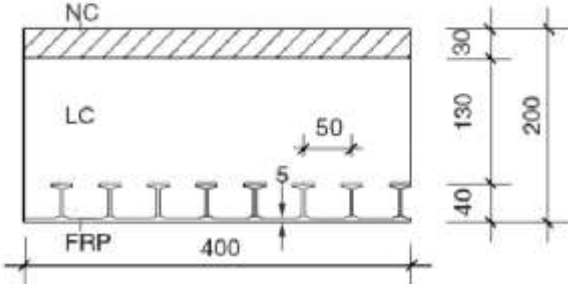


Placing of FRP Planks between the girders

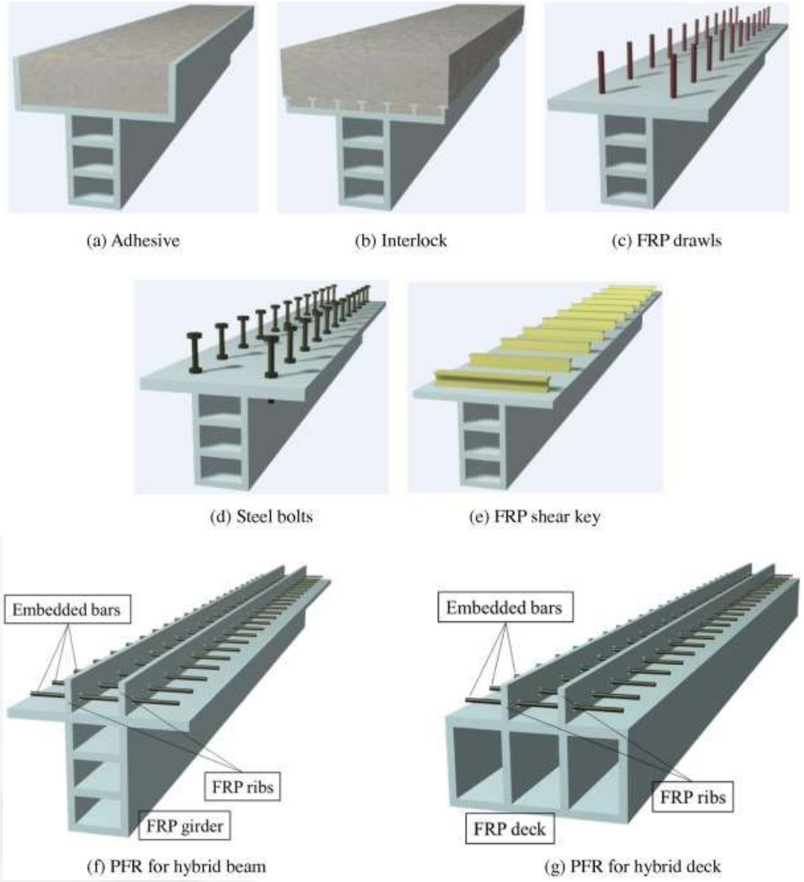
HYBRID FRP PANELS

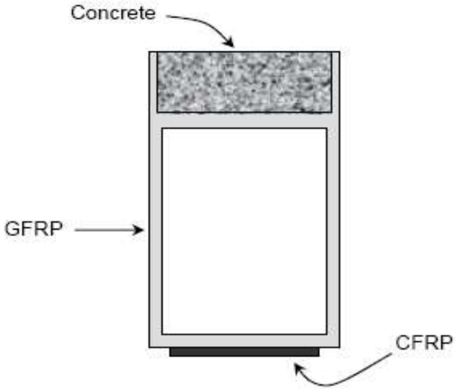
In Hybrid FRP panels light weight concrete/foam based concrete used as cor e material over a thin layer of normal concrete will be used. Figure shows the Hybrid FRP panels. The bottom most FRP planks are offering better resistan ce to tension and the top most concrete layer offers resistance to compressio n. The inner core resists the shear force and acts as insulated materials. This principle increases the stiffness and strength without increasing the density o f the elements.



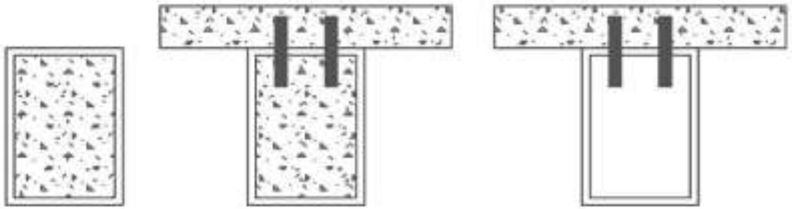


FRP Box Beam with Concrete in the Compression Zone

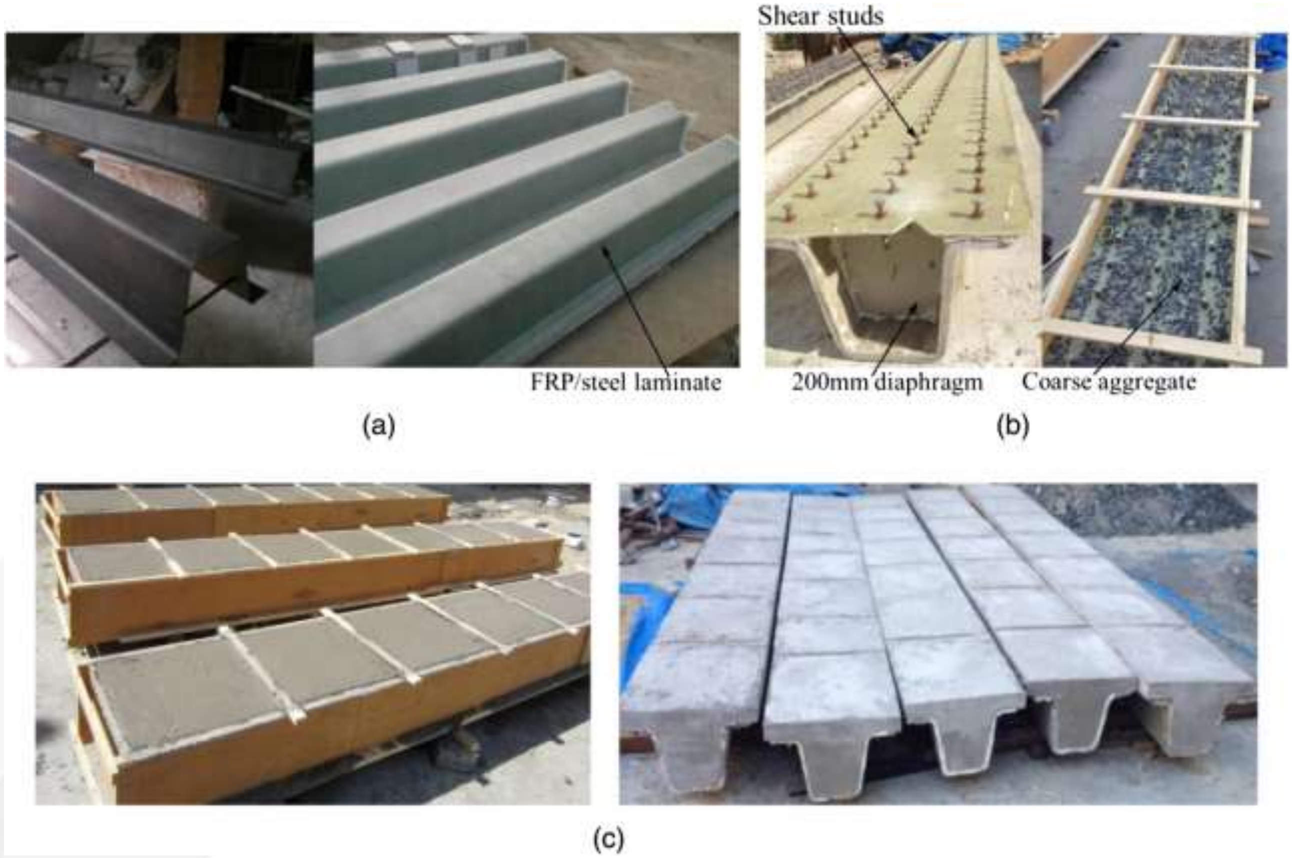




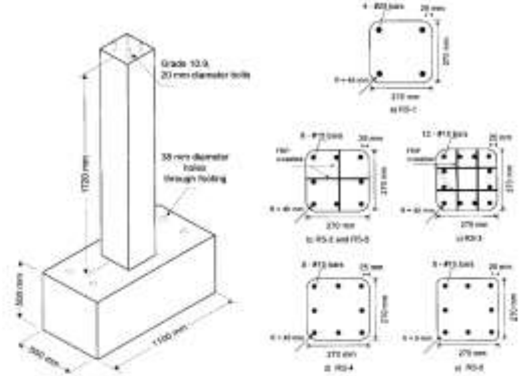
GFRP-concrete hybrid flexural member (Deskovic *et al.* 1995)

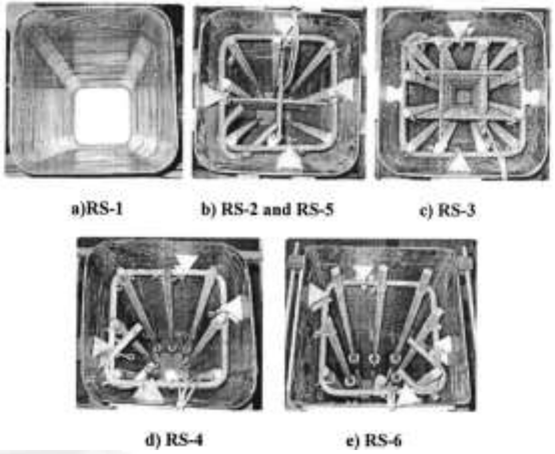


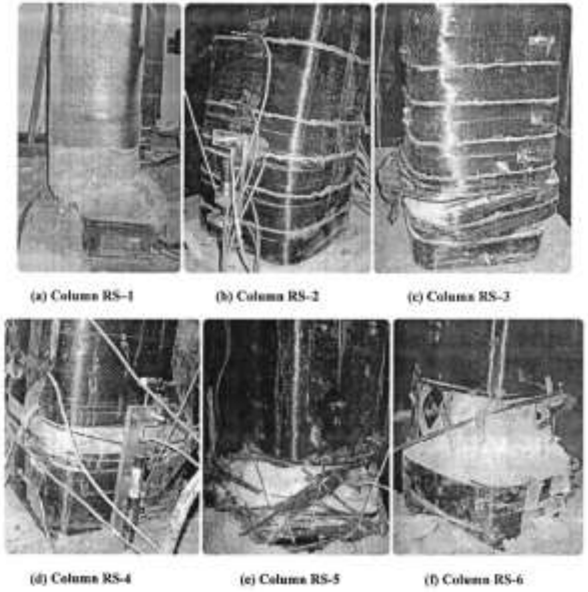
Concrete-filled FRP tubes with a concrete slab on top
(Fam and Skutezky, 2006)

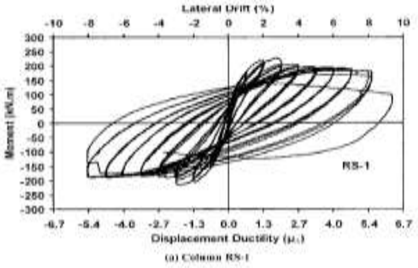

Shear studs
FRP/steel laminate
200mm diaphragm
Coarse aggregate
(a)
(b)
(c)

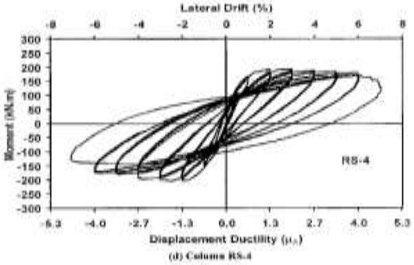
Structural Behavior of Column Constructed using FRP SIP Formwork





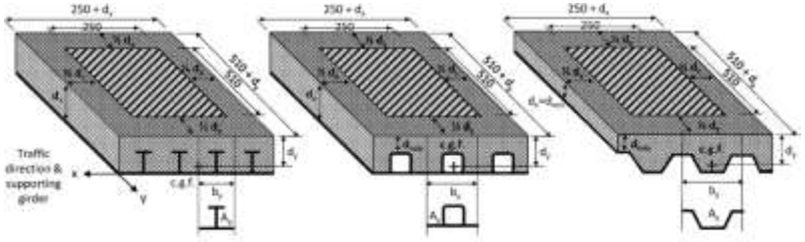






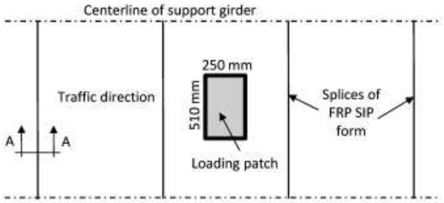
Design Equations for Concrete Bridge Decks with FRP Stay-in-Place Structural Forms

Martin Noël[1] and Amir Fam, M.ASCE[2]

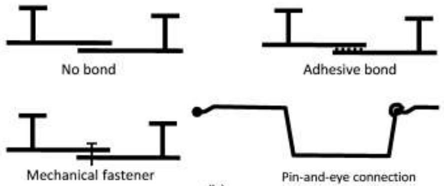


(a)

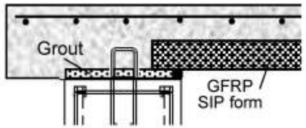

(b)



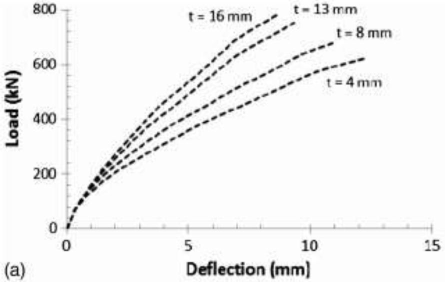
(a)



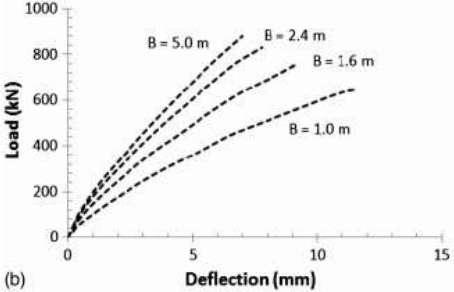
(b)



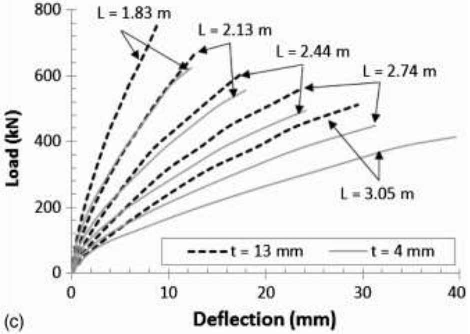
(c)



(a)



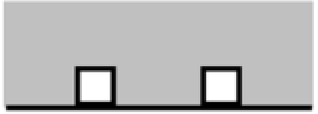
(b)



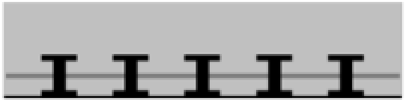
(c)

Common Detailing used in FRP SIP System

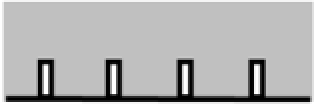
T-up Stiffeners on Plate



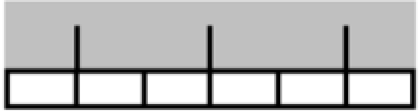
Tubular Sections on Plate



FRP Grid Bonded to a Plate

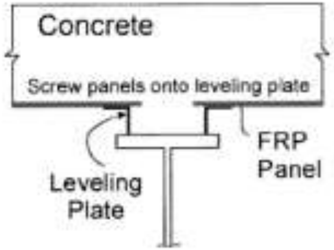


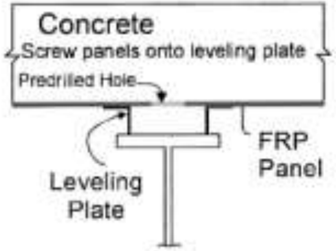
Ribbed Plate

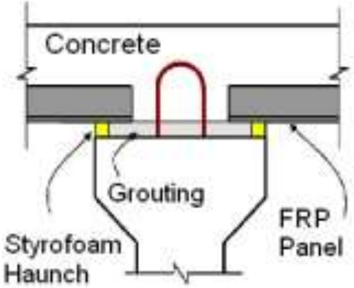


Dual Cavity System

Corrugated Plate Formwork



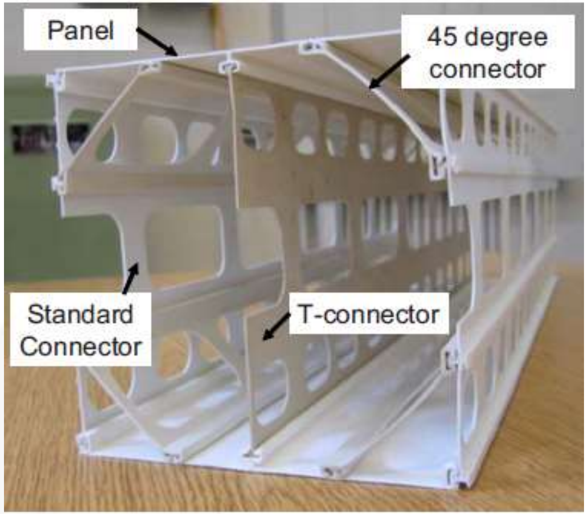




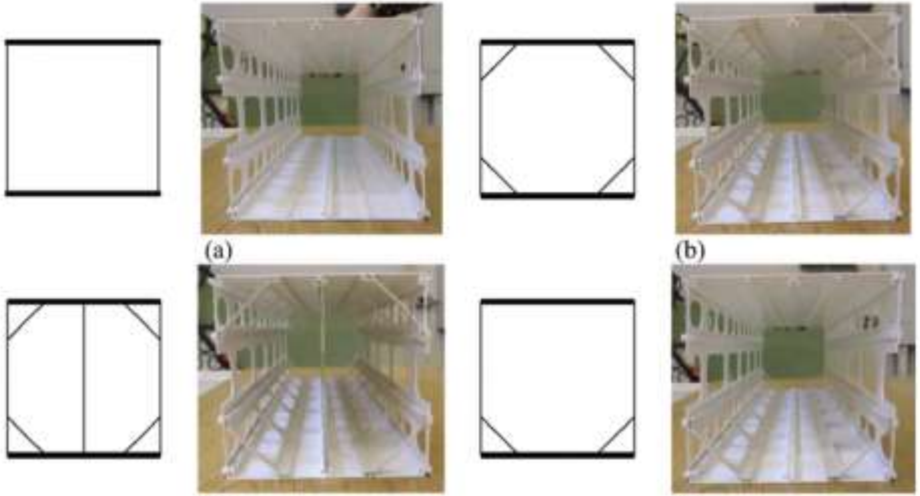
Effect of PVC Stay-In-Place Formwork on Mechanical Performance of Concrete

JOURNAL OF MATERIALS IN CIVIL ENGINEERING © ASCE / JULY 2009

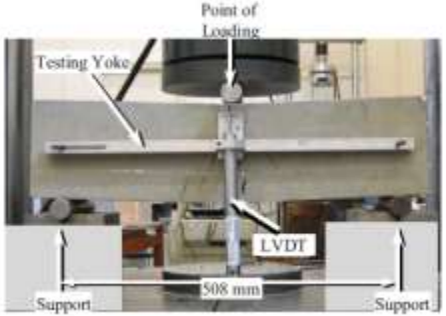
Katherine G. Kuder[1]; Rishi Gupta[2]; Corinne Harris-Jones[3]; Richard Hawksworth[4]; Sean Henderson[5]; and Jason Whitney[6]

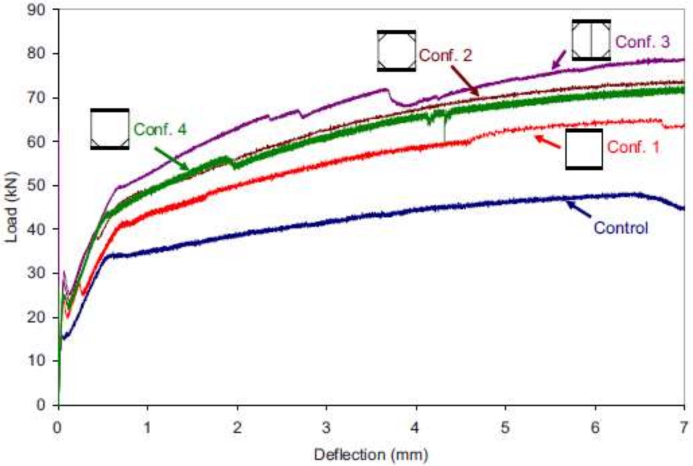


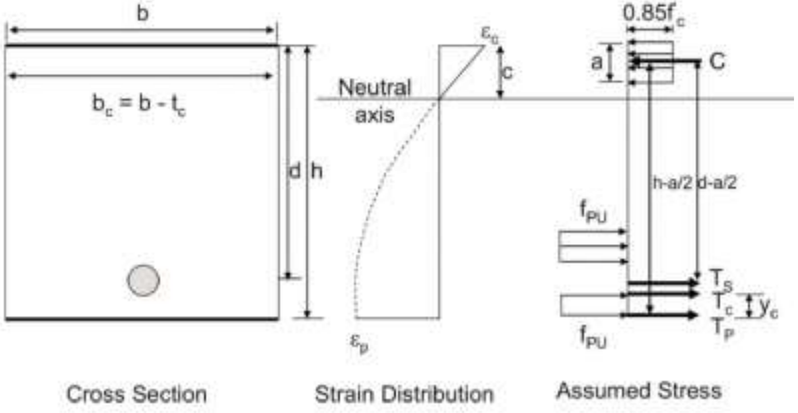
Octaform cell



(a) (b) (c) (d)







$$C = 0.85 f'_c a b_c \qquad (1)$$

$$T_s = A_s f_y \qquad (2)$$

$$T_c = A_c f_{pu} \qquad (3)$$

$$T_p = A_p f_{pu} \qquad (4)$$

$$\mathrm{M_n} = A_s f_y\left(d - \frac{a}{2}\right) + A_p f_{pu}\left(h - \frac{a}{2}\right) + A_c f_{pu}\left(h - y_c - \frac{a}{2}\right)$$

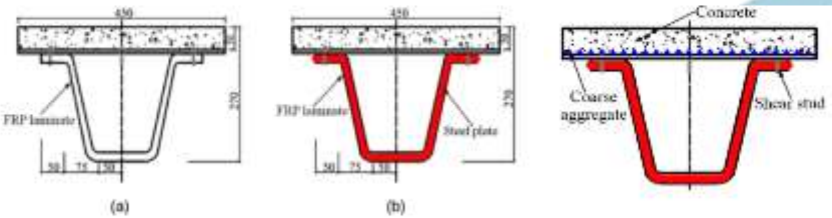
By equilibrium, the depth of the concrete stress block is

$$a = \frac{(A_c + A_p) f_{pu} + A_s f_y}{0.85 f'_c a b_c}$$

Fracture Mechanism and Damage Evaluation of FRP/Steel–Concrete Hybrid Girder Using Acoustic Emission Technique

Fangzhu Du[1]; Dongsheng Li[2]; and Yunyu Li[3]

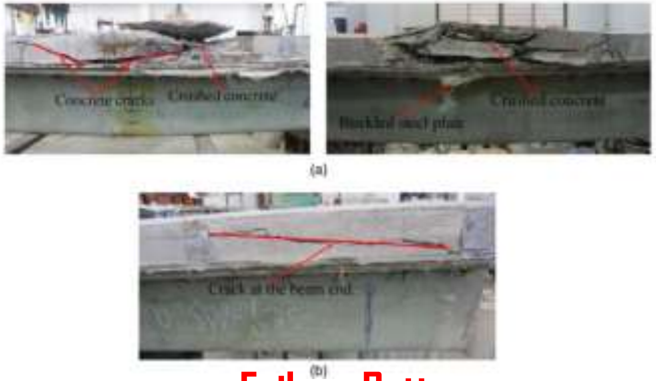
J. Mater. Civ. Eng., 2019, 31(7): 04019111



Specimen Details

Test Setup

Failure Pattern

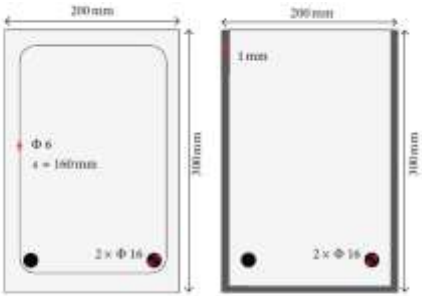


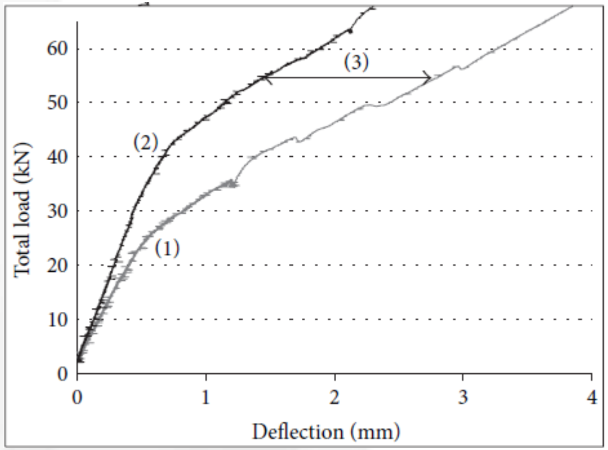
Failure Pattern

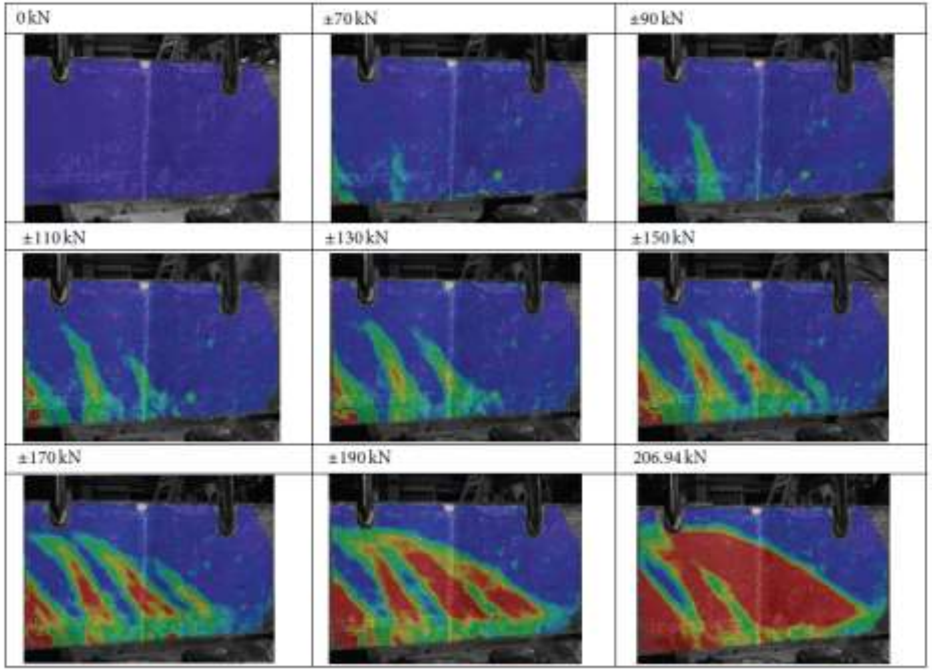
Stay-in-Place Formwork of TRC Designed as Shear Reinforcement for Concrete Beams

SIP - Textile Reinforced Concrete

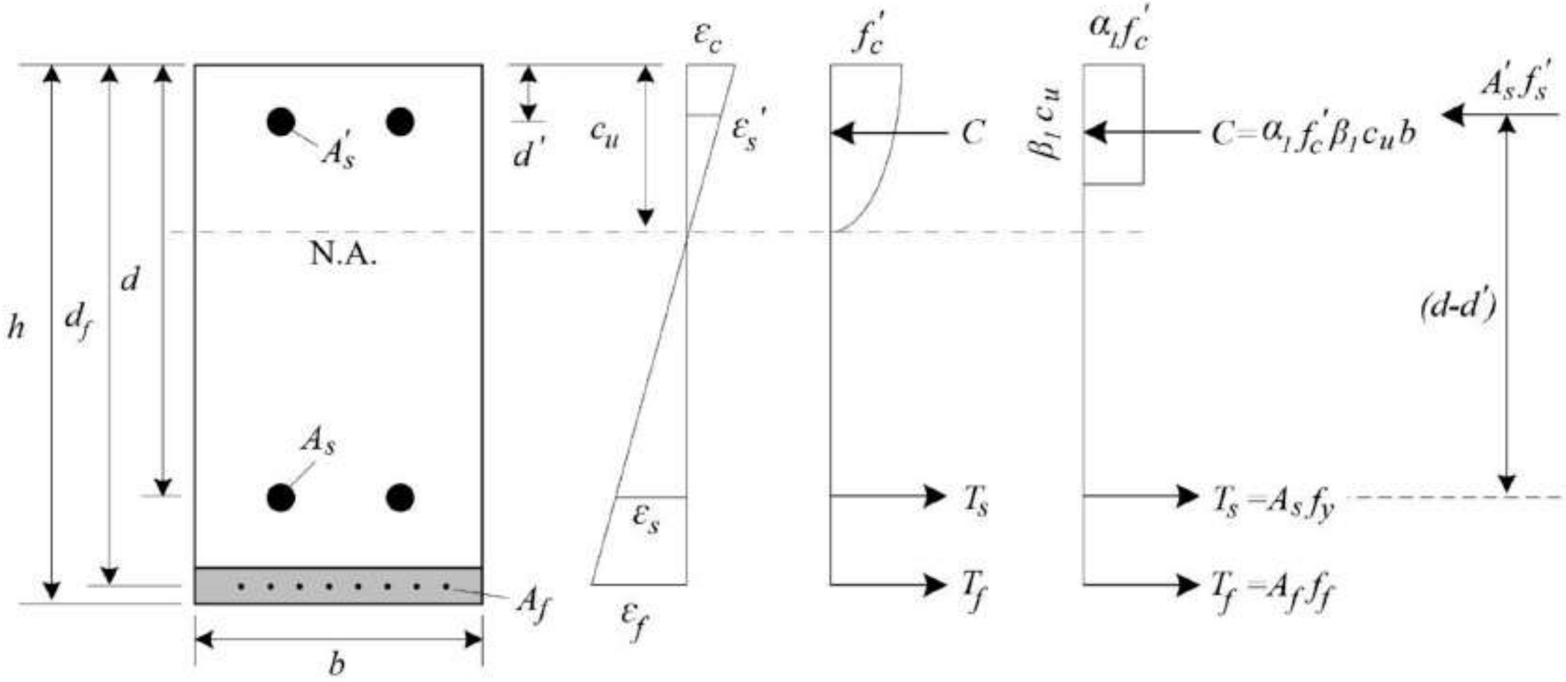
S. Verbruggen, O. Remy, J. Wastiels, and T. Tysmans

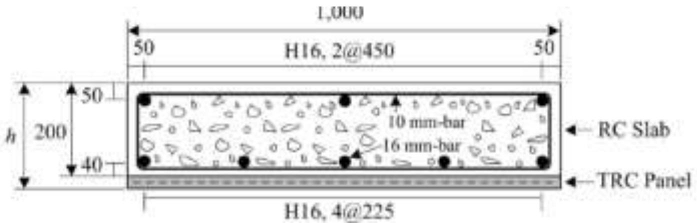






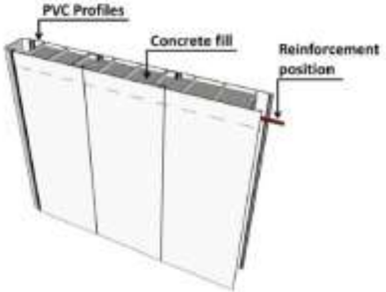
Internal Stress and Strain Distributions of RC Element casted on TRC -SIP

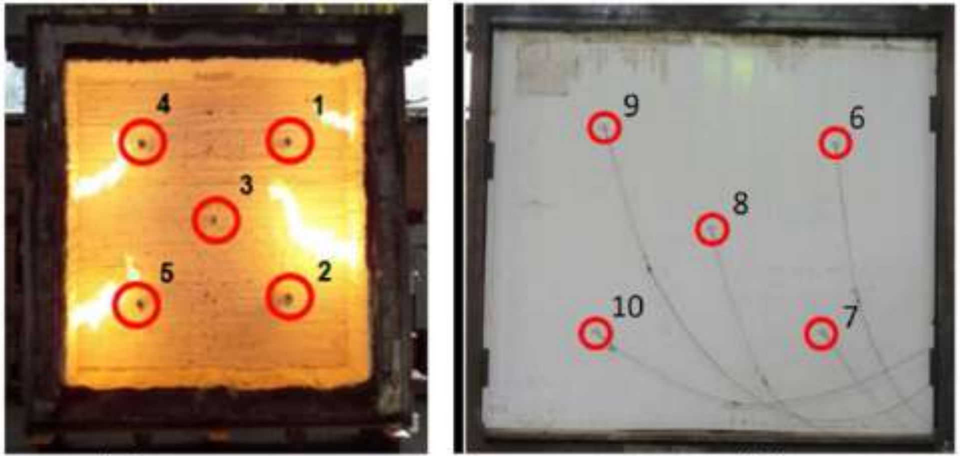




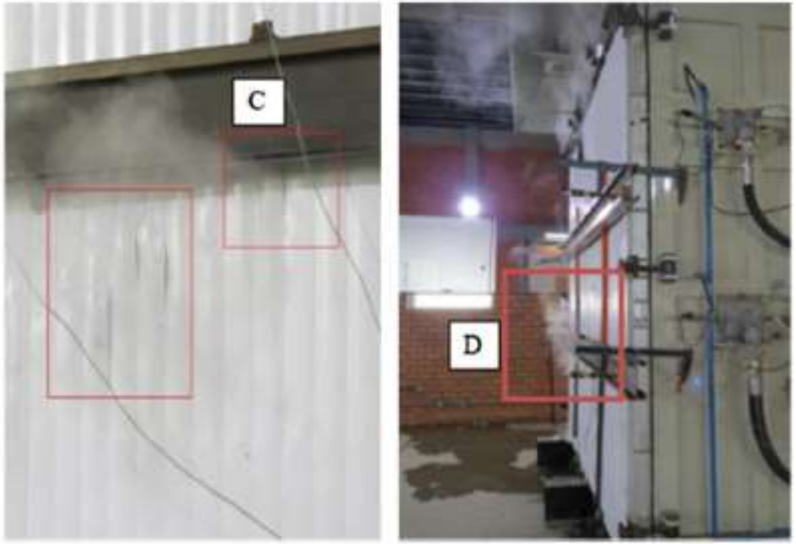
Fire resistance performance of concrete-PVC panels with polyvinyl chloride (PVC) stay in place (SIP) formwork

Michel Murillo A.[a,b,*], Bernardo F. Tutikian[c], Vinicius Ortolan[c], Marcos L.S. Oliveira[d], Carlos H. Sampaio[e], Leandro Gómez P[a], Luis F. Silva O[a]





(a) (b)



Sample	Before exposure to fire	After exposure to fire
PVC1		
PVC2		
PVC3		

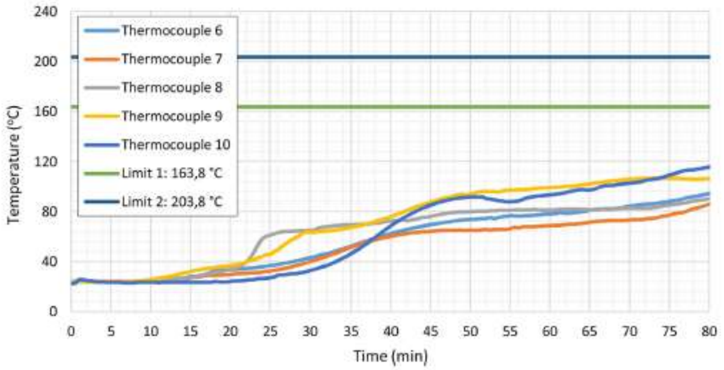


Fig. 9 – Temperature measurements recorded by the thermocouples on the external face of the PVC2 sample.

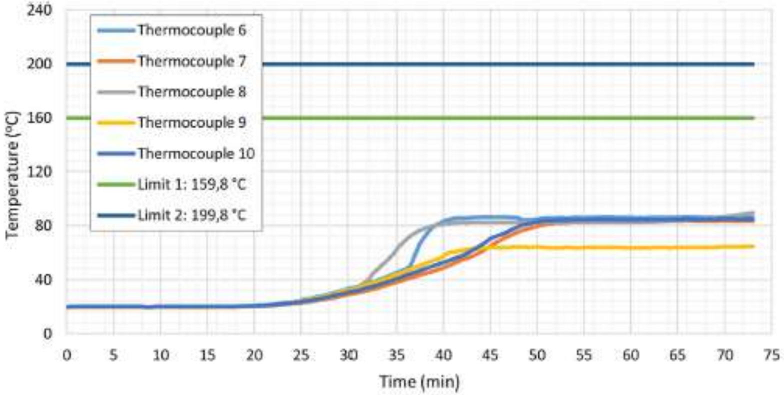


Fig. 10 – Temperature measurements recorded by the thermocouples on the external face of the PVC3 sample.

Lateral Pressure on Wall Formwork

$$P_m = C_w C_c [150 + 9000R / T]$$

lateral pressure for wall having the placement height less than or equal to 14 ***f_t*** having rate of placement less than 7***f_t/hr***.

P_m = maximum lateral pressure, ***lb/$s_q$ft***
C_w = unit weight coefficient
C_c = chemistry coefficient
R = rate of fill of concrete in form, ***f_t/hr***
T = temperature of concrete in form, °F

For all wall forms with concrete placement rate from 7 to 15 f_t/*hr*, and for walls where the placement rate is less than 7 f_t/*hr* and the placement height exceeds 14 ft.

$$P_m = C_w C_c [150 + 43400 / T + 2800 R / T]$$

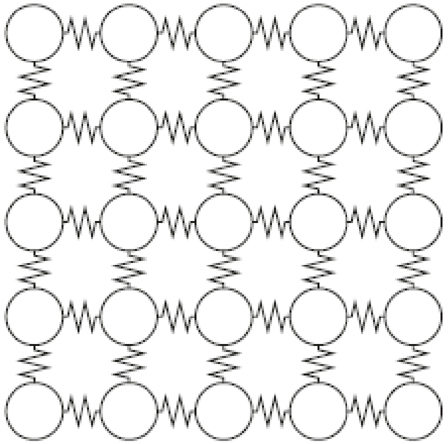
Thank you

Outline of Presentation

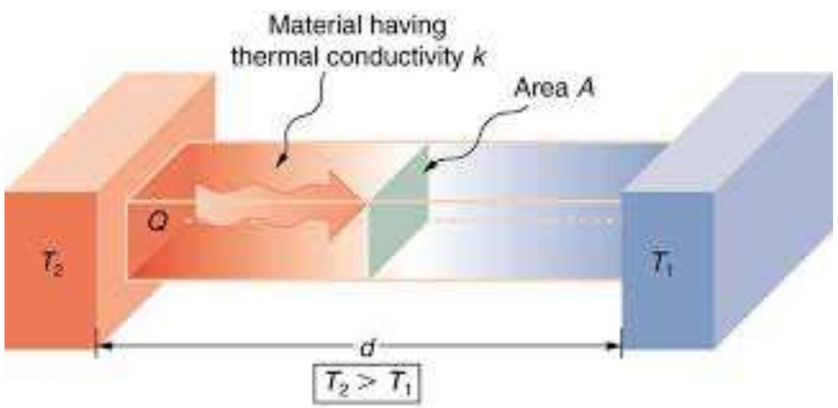
1. Steady and unsteady Heat Flow through Buildings
2. Thermal Admittance and decrement factor
3. Mean temperature in the space
4. Fluctuating Heat gains and Internal temperature
5. ECBC Codal Provisions & expt. Evaluation
6. Temperature Monitoring in Building-A case Study

Heat Transfer- Conduction

- Heat transfer by conduction involves transfer of energy within a material without any motion of the material as a whole.
- The rate of heat transfer depends upon the temperature gradient and the thermal conductivity of the material.

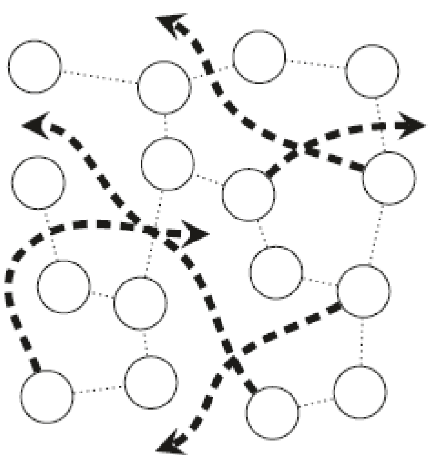


Particles are held together very closely by strong electromagnetic forces

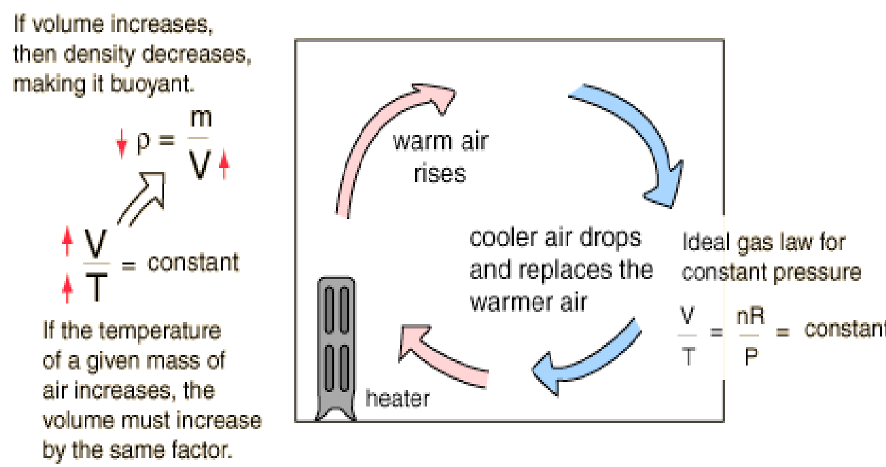


Heat Transfer-Convection

- Heat transfer by mass motion of a fluid such as air or water when the heated fluid is caused to move away from the source of heat, carrying energy with it.
- Convection above a hot surface occurs because hot air expands, becomes less dense. Hot water is likewise less dense than cold water and rises, causing convection currents which transport energy.



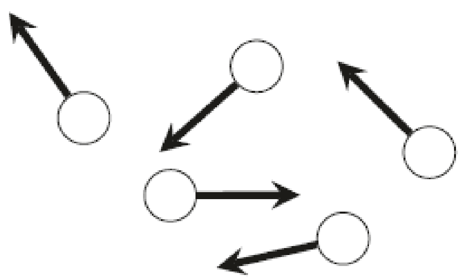
Particles are quite close to each other and irregularly connected by weak electromagnetic forces that are easily broken and re-established.

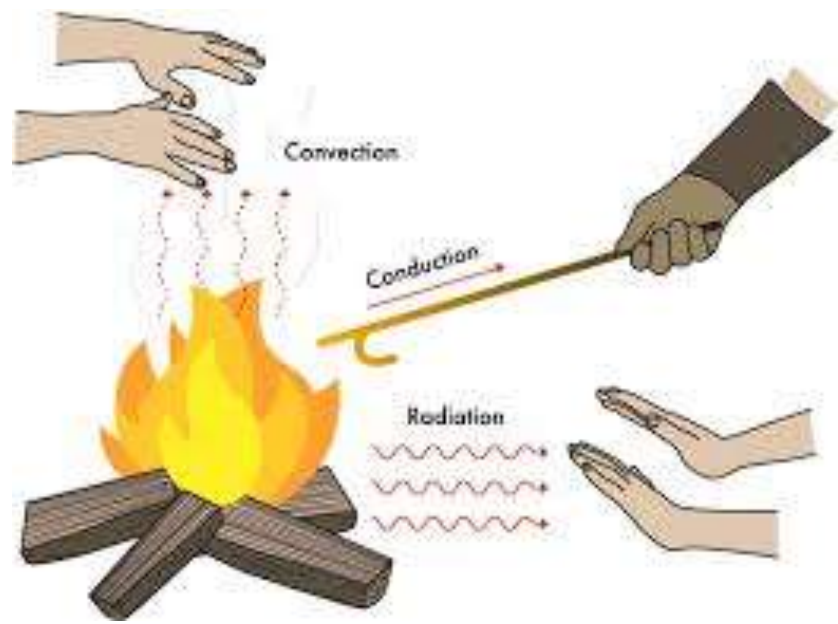


Definition and diagram from: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heatra.html#c3

Heat Transfer- Radiation

Radiation is heat transfer by the **emission of electromagnetic waves which carry energy away from the emitting object**.

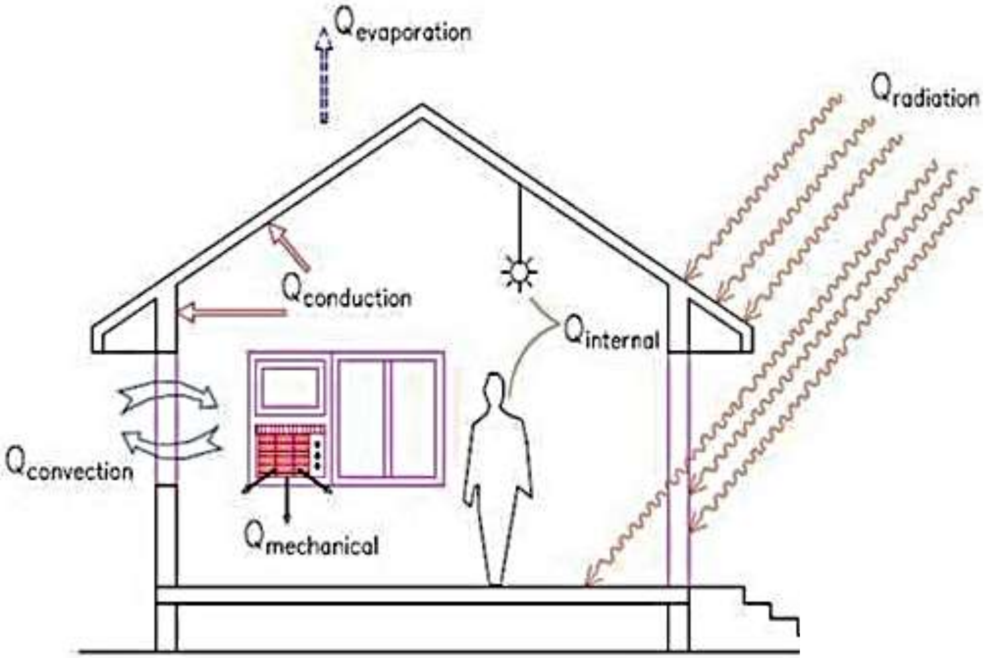




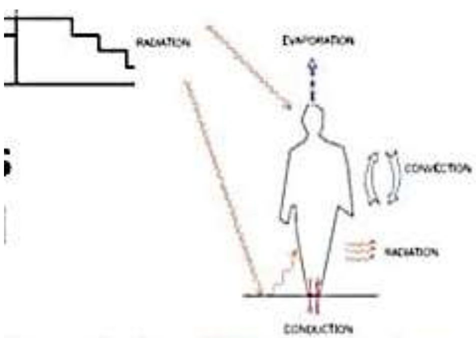
There are no forces between them except for occasional collisions. They move around freely and quickly.

Definition and diagram from: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heatra.html#c3

Heat Flow through Building Envelope



Hest Exchange Processes Between A Building And External Environment



human body and the indoor environment

Qs- Direct Solar radiation

Qc- heat flow through Conduction

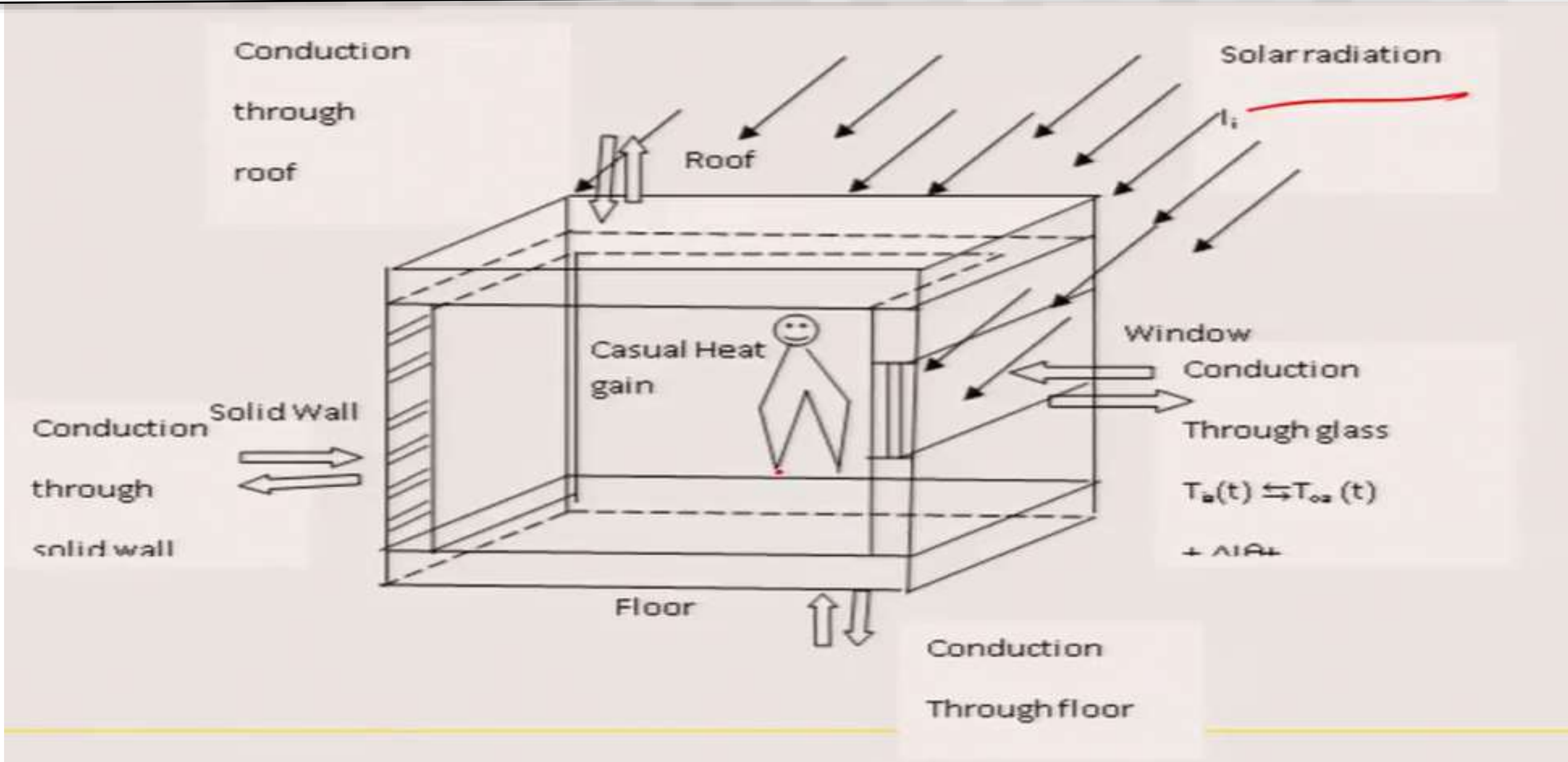
Qv- Heat flow through Ventilation

Qi- heat generated through body, equipment's

Qe- Heat Evaporation/emission during night

.

Heat Flow through Building Envelope



Qs- Direct Solar radiation

Qe- Heat Emission during night

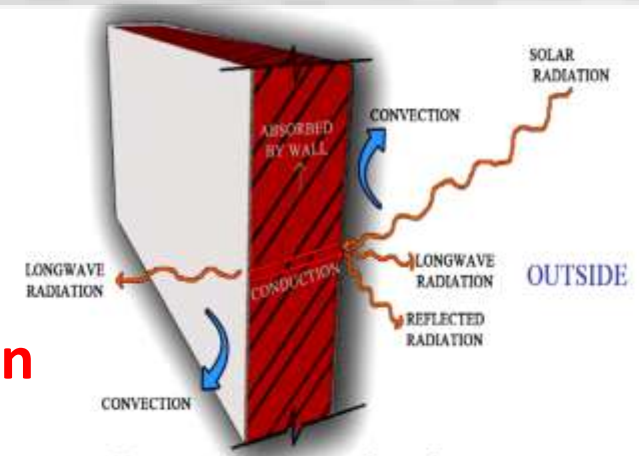
Qc- heat flow through Conduction

Qv- Heat flow through ventilation

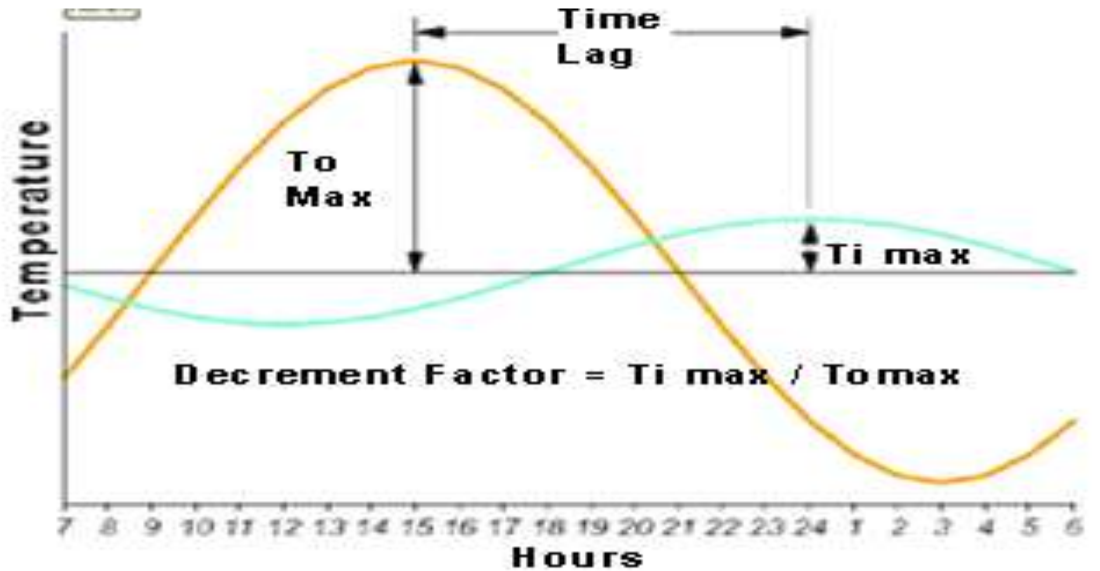
Qi- heat generated through body, equipment's..

Heat Flow Path

- Steady state: Temperature is constant at any time
- Transient Conduction/Dynamic /non-steady State)- Temperature at any location in a region changes with time



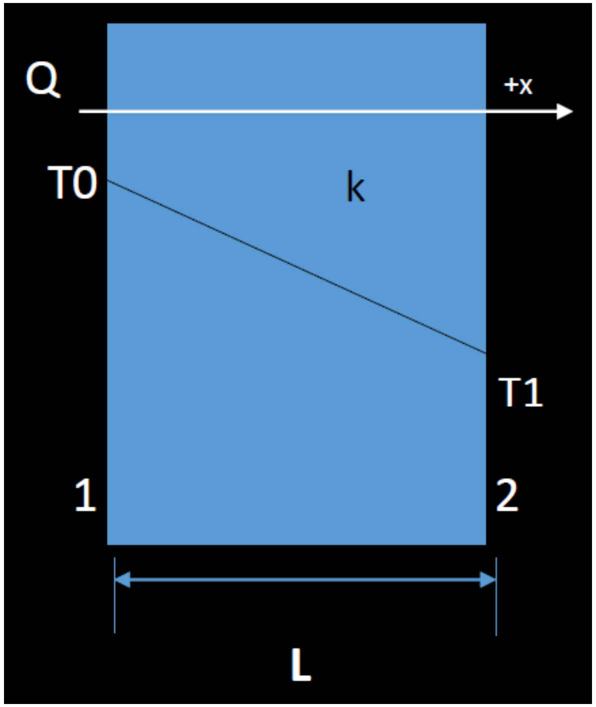
Heat transfer process through wall section



Thermal Mass Introduces Time Lag Decrement Factor

HEAT CONDUCTION THROUGH A PLANE WALL

Let us consider a plane wall of homogeneous material through which heat is flowing in x-direction.,



Let,

L = thickness of the wall

A = cross-sectional area of the wall

k = thermal conductivity of wall material

T_0 ,T1 = temperature maintained at surfaces 1 and 2

ΔT- Temp difference inside and outside

α - Thermal diffusivity

HEAT CONDUCTION THROUGH A PLANE WALL

General heat conduction equation is:, (Fourier-Biot equation)

$$\partial^2 T/\partial x^2 + \partial^2 T/\partial y^2 + \partial^2 T/\partial z^2 + q/k = 1/\alpha * \partial T/\partial t$$

For one dimensional steady state system ($\partial T/\partial t$) = 0

With no heat generation (q/k)= 0

One dimensional flow , $\partial^2 T/\partial y^2 = \partial^2 T/\partial z^2 = 0$

Then, heat equation will be $\partial^2 T/\partial x^2 = 0$

$$d^2 T/dx^2 = 0$$

Integrating above equation,

$$dT/dx = C_1$$

Integrating it again,

$$T = C_1 x + C_2$$

Where C_1 and C_2 are arbitrary constants

Steady Heat Flow through wall

- At $x = 0$; $T = T_0$
- At $x = L$; $T = T_1$

From the expression derived above $T = C_1.x + C_2$ …………(1)

At $x = 0$;

$$T_0 = C_1 (0) + C_2$$

$$C_2 = T_0$$

At $x = L$;

$$T_1 = C_1 . L + T_0$$

$$C_1 = (T_1 - T_0)/L$$

Eqn. 1 can be re-written as

$$T = (T_1 - T_0/L) . x + T_0$$

i.e temperature varies linearly with x

Steady Heat Flow through wall

- ***Inference:***

1. Temperature distribution across the wall is linear.

2. Temperature distribution is independent of k.

From Fourier's Law of heat conduction, we have,

Heat flow $Q = -k\,A\,dT/dx$

$$dT/dx = d/dx\ \left((T_1 - T_o)/L * x) + To\right) = (T_1 - T_o)/L$$

Fourier's Law can be re-written as,

$$Q = -k\,A\,(T_1 - T_o)/L$$

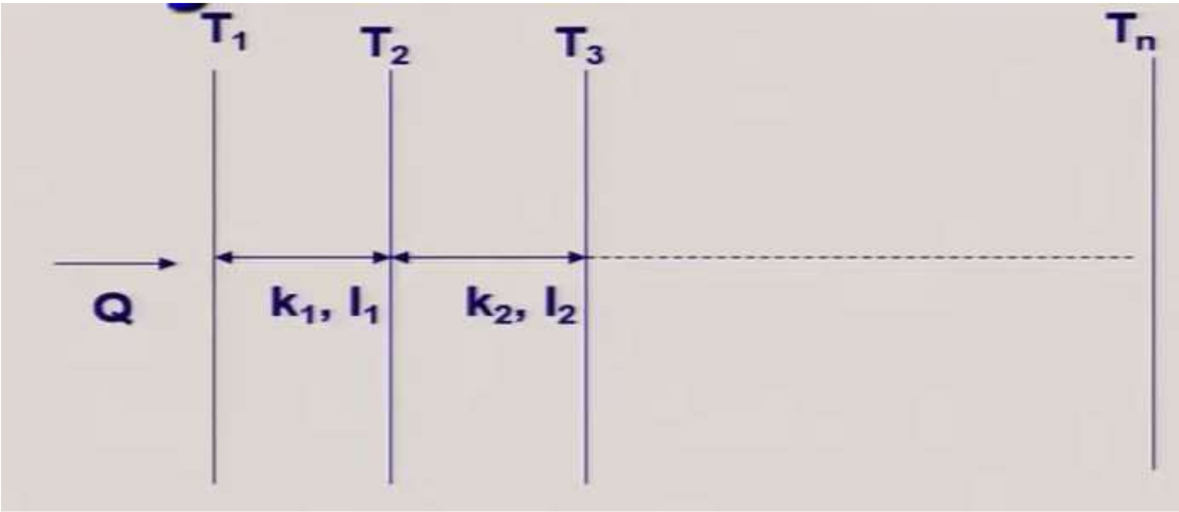
$$Q = -\,A\,U\,(T_1 - T_o)$$

Where, k- Thermal Conductivity W/mk

L/kA = Thermal Resistance of heat conduction (R) = (L/kA)

U- Thermal Transmittance, $W/m^2K = 1/R$

Steady Heat Flow through layered wall



Layers may include cavity or insulation. Cavity R is used

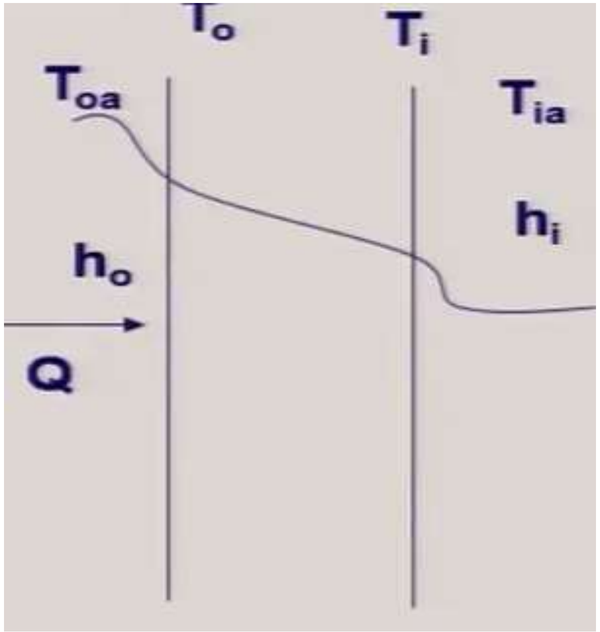
$Q = k_1 A \frac{(T_1 - T_2)}{l_1} = k_2 A \frac{(T_2 - T_3)}{l_2} = \ldots\ldots\ldots$

$T_1 - T_2 + T_2 - T_3 \ldots\ldots T_n = Q/A\, [l_1/k_1 + l_2/k_2 + \ldots\, l_{n-1}/k_{n-1}]$

$T_1 - T_n = (Q/A) x\, R$

$R = R_1 + R_2 + \ldots\ldots$

Steady Heat Flow through layered wall



U- Thermal Transmittance, W/m²K
h_o and h_i - Surface heat transfer coefficients

Q = h_o A $(T_{oa} - T_o)$ = h_i A $(T_i - T_{ia})$= (1/R) x $(T_o - T_i)$ A

1/U = $1/h_o + l_1/k_1 + l_2/k_2 + .. l_{n-1}/k_{n-1} + 1/h_i$

Q = UAΔT

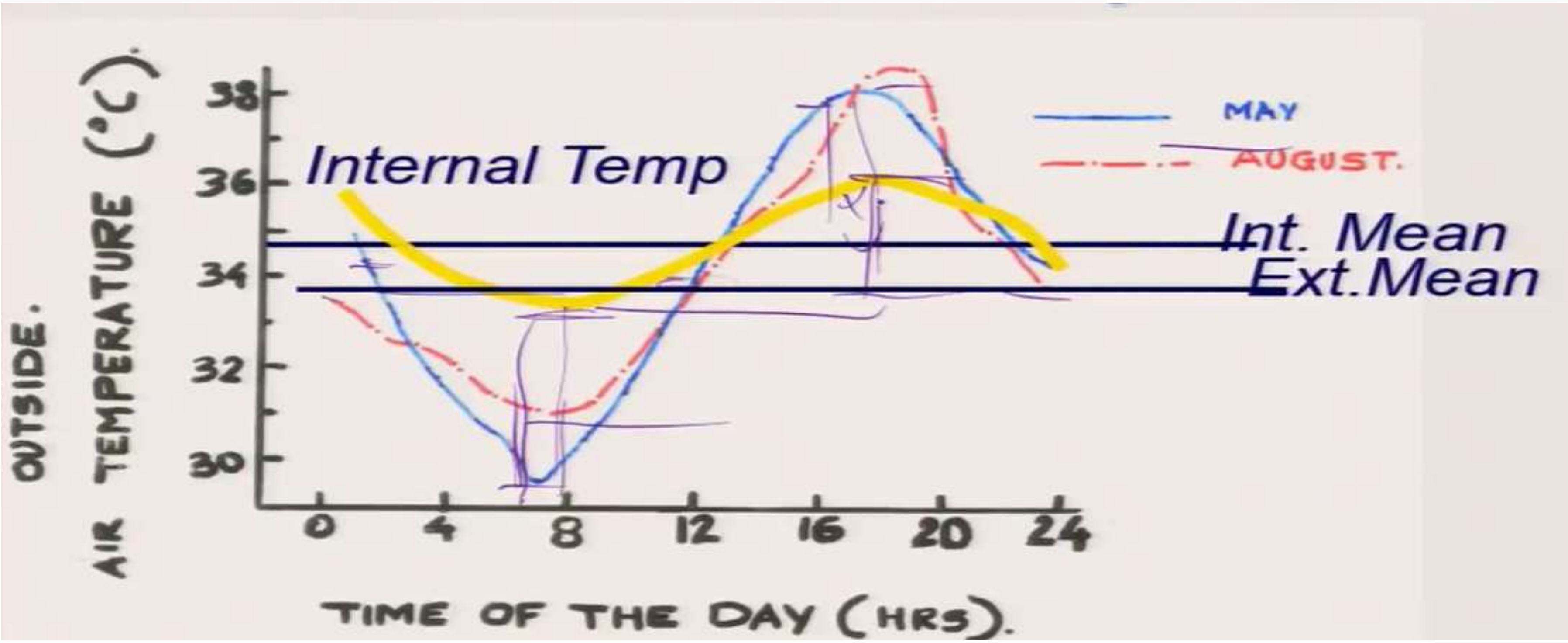
Steady Heat Flow through wall

Different surfaces are exposed same temperature gradient

Q = $[U_1A_1 + U_2A_2 \ldots](T_{oa} - T_{ia})$

UA = $[U_1A_1 + U_2A_2 \ldots]$

External and Internal Temperature



Due to periodic nature the temperature can be expressed as a mean temperature and a fluctuating component.

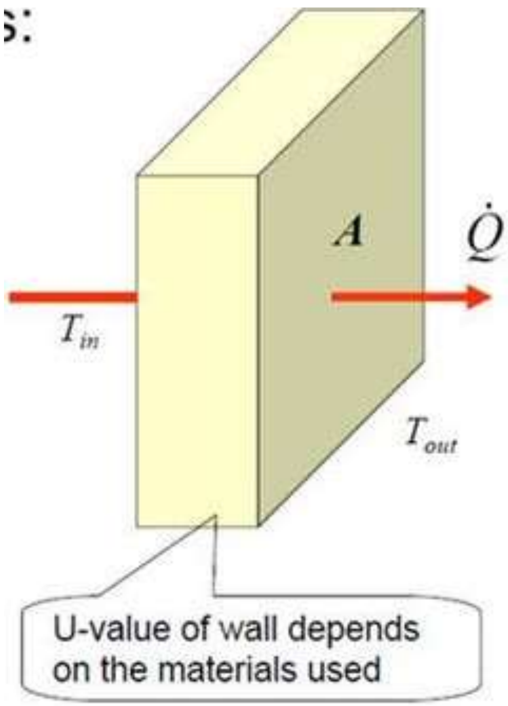
i.e. T_{oa} (t) = $\bar{T}_{oa}$ + fluctuation

&T_{ia} (t) = $\bar{T}_{ia}$ + fluctuation

Steady Heat Flow

- For conducting in steady state, heat exchange (Q_{cd})

$$Q_{cd} = \sum U_j A_j \, (T_{oa} - T_{ia})$$



Effect of Radiation on opaque surface

- For unit area, heat absorbed by a surface = α I

After reaching steady state temperature (say at equivalent temperature t_{oe}),

The Heat Absorbed = Heat Dissipated

- i.e. α I $= h_o(T_{oe} - T_{oa})$

α I $/h_o$ = Sol- air excess

$T_{oe} = T_{oa}$ + α I $/h_o$

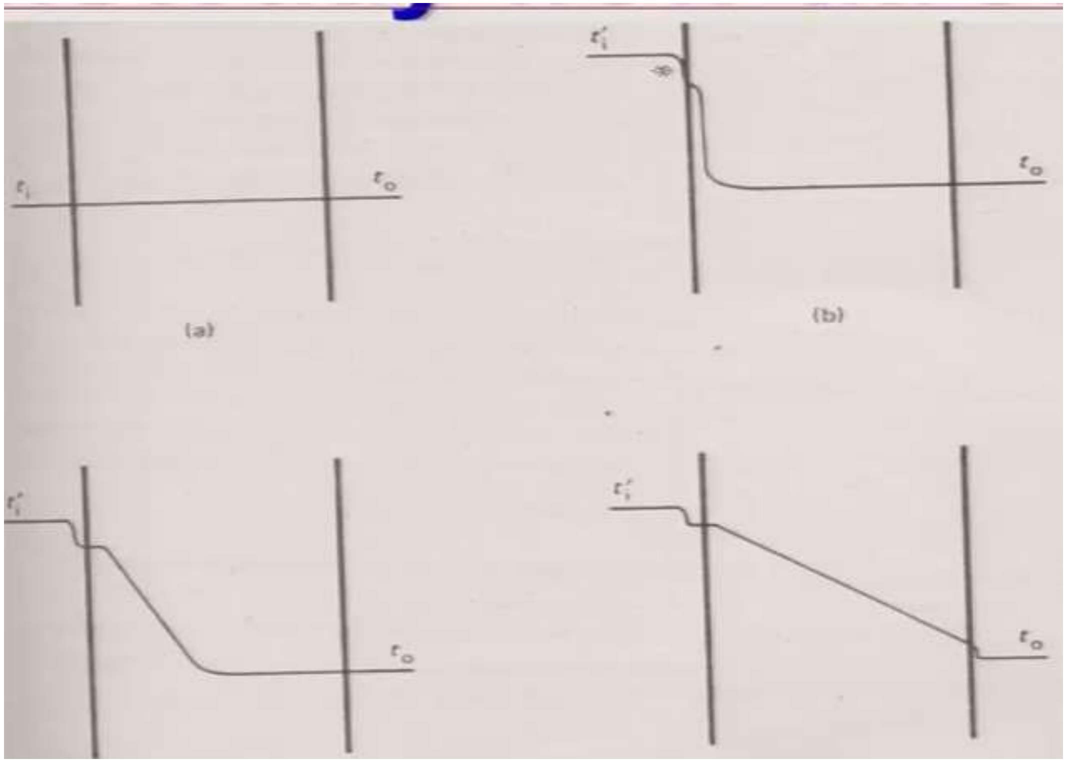
α = Absorptivity of surface

T_{oe} = Sol-air temperature

T_{oa} = Outside air temperature

h_o = surface heat transfer coefficient

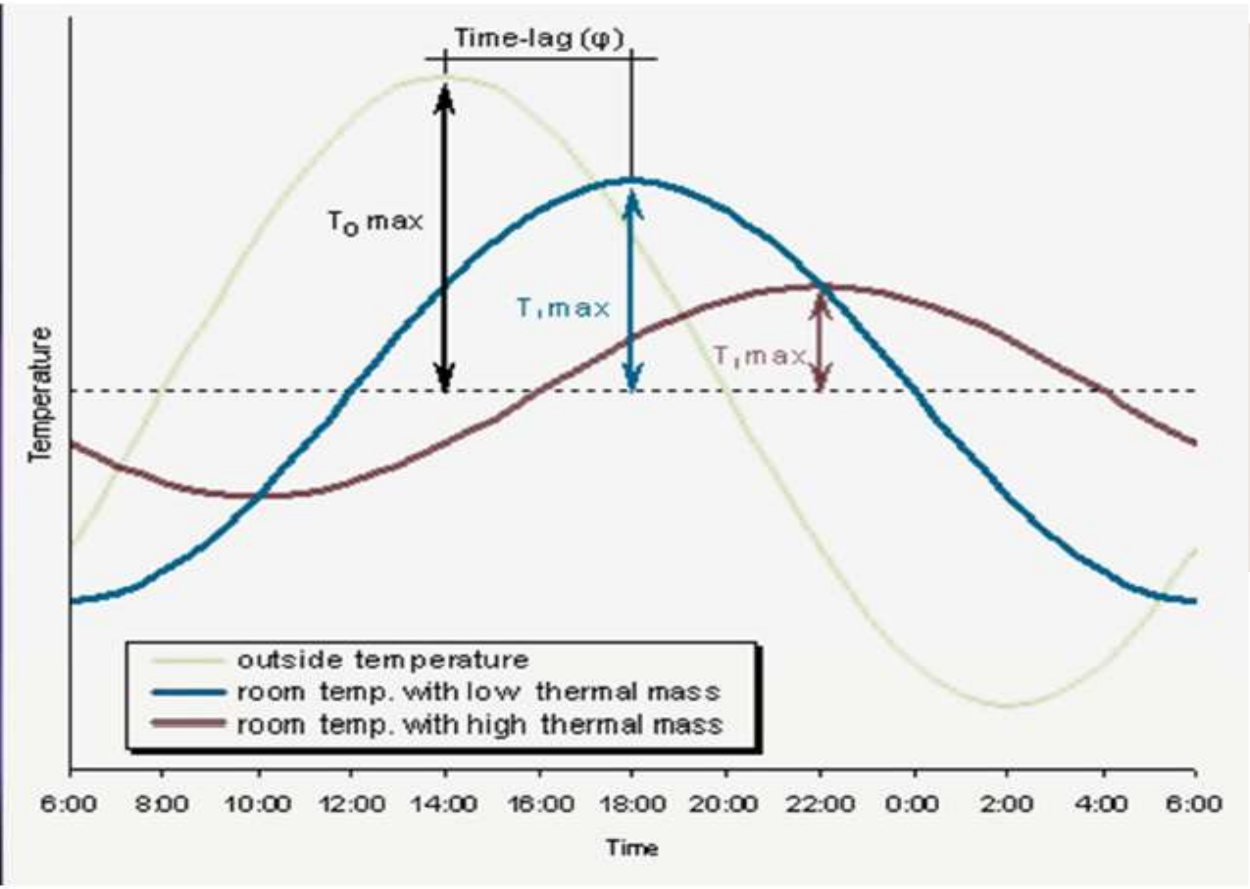
Temperature Gradient at different times

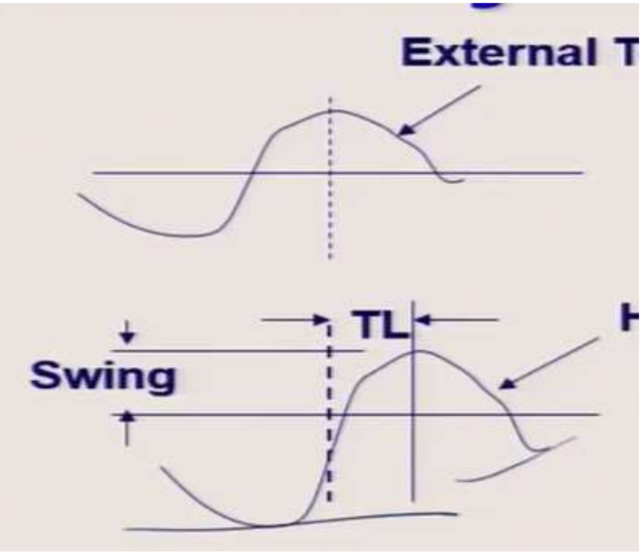


In (a)Temperature within the system does vary with time

In (b-d) Due to heat storage capacity of material Unsteady flow occur

Unsteady Heat Flow through wall





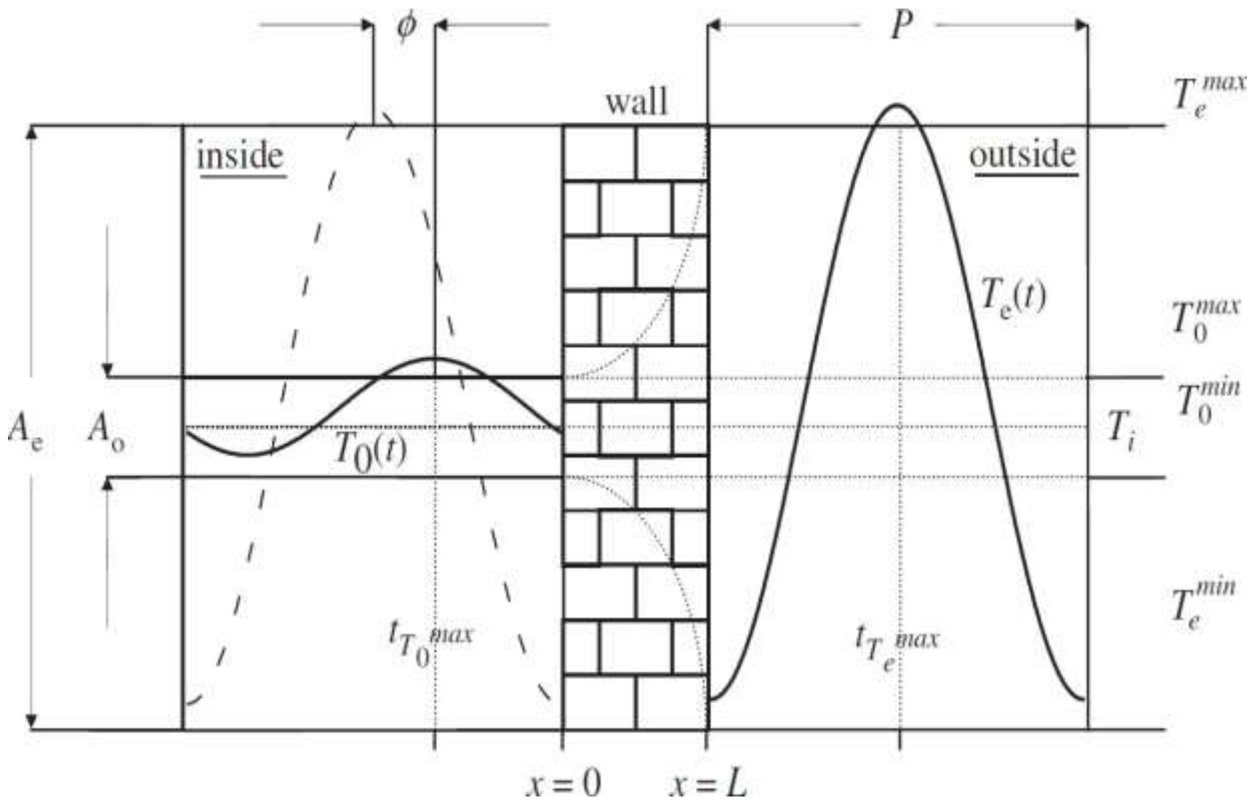
a) Light wall b) Heavy wall

TL: Time lag & Swing depends on thermal capacity i.e., Density x Specific heat

Thermal Mass

- Thermal mass is a term used in solar passive design to describe materials that have the ability to absorb and store heat.
- Solar efficient homes incorporate thermal mass in order to remain warm overnight and through periods of cold or cloudy weather
- High density materials such concrete, bricks, and tiles require a great deal of heat energy to change their temperature and are therefore said to have high thermal mass. Lightweight materials, on the other hand, such timber, have low thermal mass.

Time Lag ø and Decrement factor f



Important characteristics to determine the heat storage capabilities of any material

The time (hour, h) it takes for the heat wave to propagate from the outer surface to the inner surface is named as "time lag (ø)" and the decreasing ratio of its amplitude during is named as "decrement factor (f)

Where,

t Tmax o time in hours when inside surface temperatures are at their maximums,

T Tmax e (h) time in hours when outside surface temperatures are at their maximums

P (24 h) is the period of the wave

Source: H Asan (2006)

Time Lag ø and Decrement factor f

The time lag may be computed as follows

$$\phi = \begin{cases} t_{T_o^{\max}} > t_{T_e^{\max}} \Rightarrow t_{T_o^{\max}} - t_{T_e^{\max}}, \\ t_{T_o^{\max}} < t_{T_e^{\max}} \Rightarrow t_{T_o^{\max}} - t_{T_e^{\max}} + P, \\ t_{T_o^{\max}} = t_{T_e^{\max}} \Rightarrow P, \end{cases}$$

The decrement factor is defined as:

$$f = \frac{A_o}{A_e} = \frac{T_o^{\max} - T_o^{\min}}{T_e^{\max} - T_e^{\min}}$$

Where,

A_o, Ae amplitudes of the wave in the inner & outer surfaces of the wall

Smaller the decrement factor, the more effective is the envelope at suppressing temperature swings.

The time lag of the heat wave should be as high as possible to delay an outside sinusoidal heat wave from entering into the room through the wall or roof.

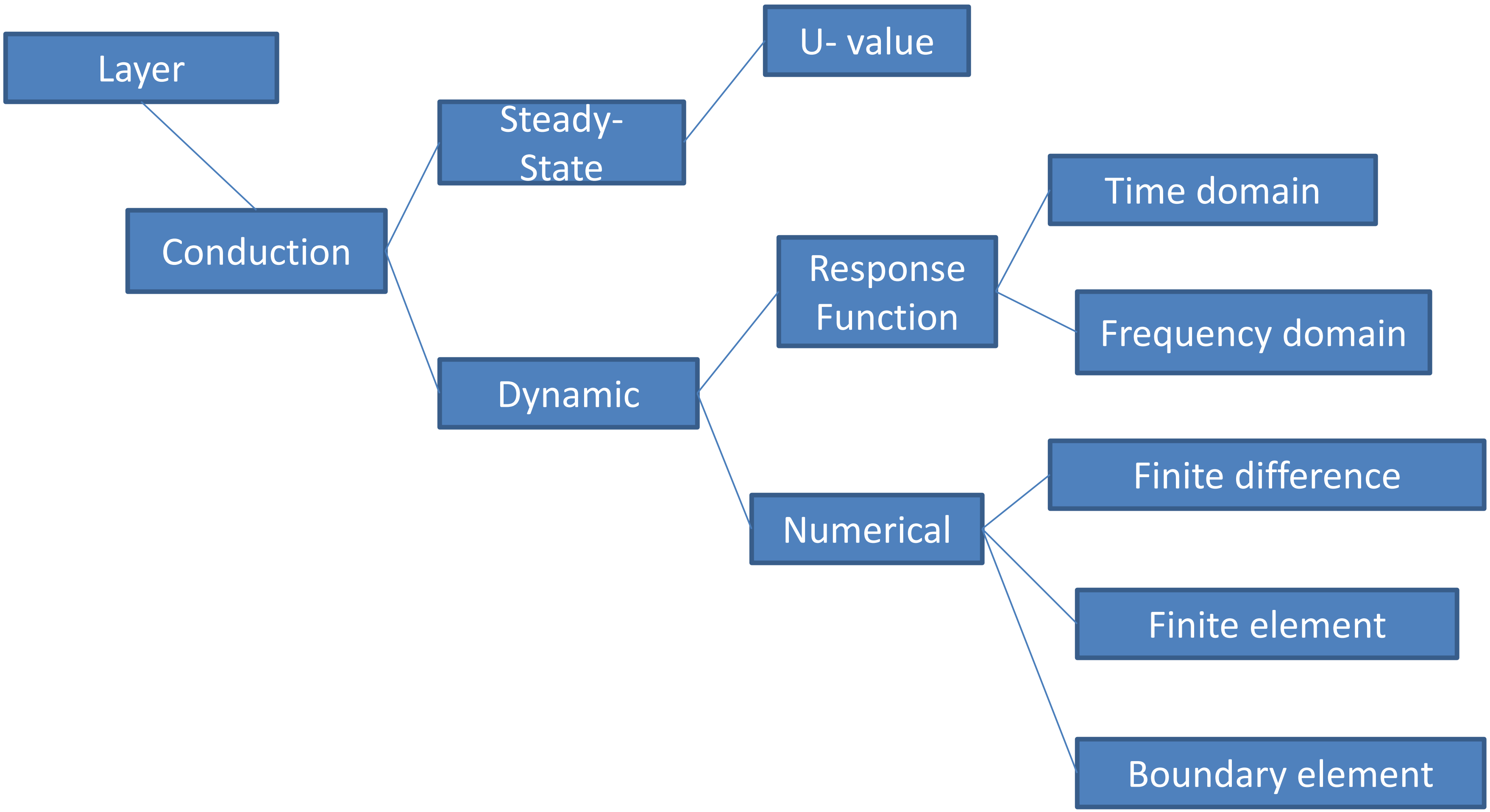
Thermal Performance

- Effect of radiation on opaque surface is taken account of through an equivalent temperature

- Short wave absorptivity (Low) and long wave emissivity (High) are also important

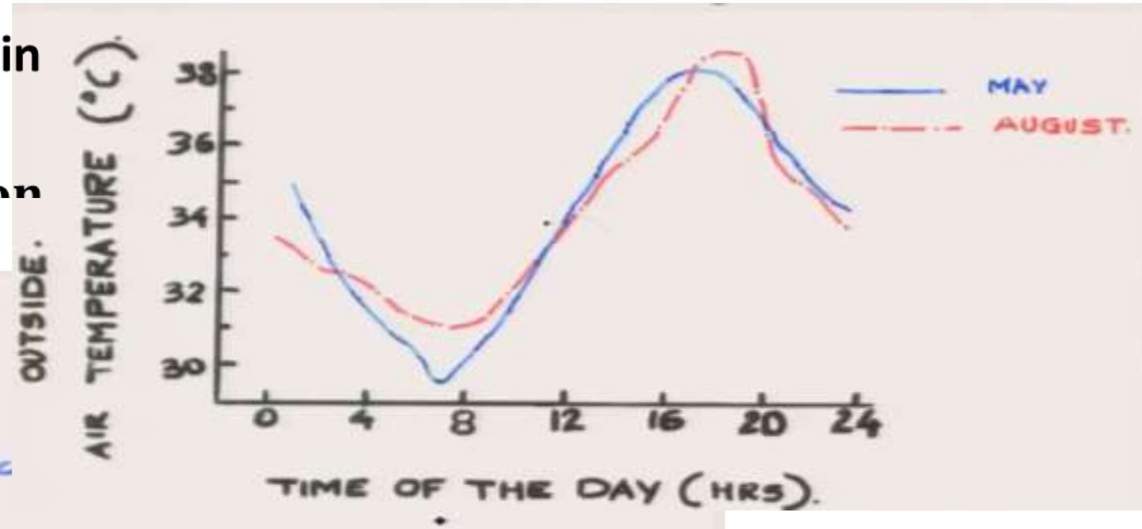
- Sequence of layer does not influence steady flow although may have effect in periodic heat flow

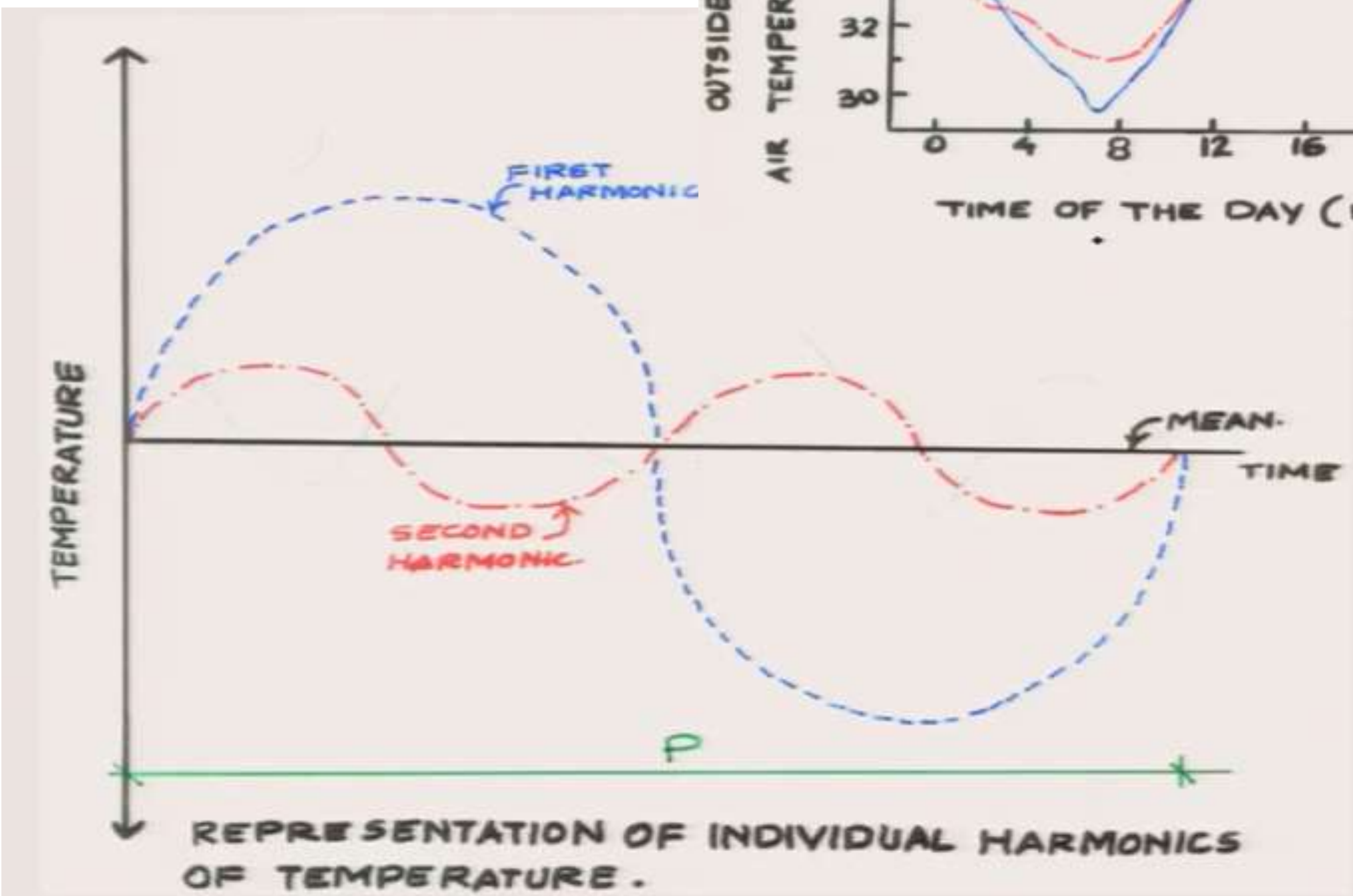
Heat Flow through Building



Harmonics

- Can be calculated by sum of sin and cosine functions…
- Fourier series of Expansion





Frequency Domain Treatment

$$T(t) = \overline{T} + \sum_{j=1}^{\infty}[a_j \cos(\frac{2\pi j}{p})t + b_j \sin\left(\frac{2\pi j}{p}\right) t]$$

$\overline{T}$ is the mean.

j corresponds to a harmonic

P is period of the fundamental (2π)

$$T(t) = \overline{T} + \sum_{j=1}^{\infty} T_j \cos(\omega_j t + \emptyset_j)$$

ω = angular frequency = $(\frac{2\pi j}{p})$

And $\emptyset$ is $\tan^{-1}(-\frac{b_j}{a_j})$

Frequency Domain Treatment

a_j, b_j *can be determined by multiplying* $\cos\left(\frac{2\pi jt}{p}\right)$ *and* $\sin\left(\frac{2\pi jt}{p}\right)$

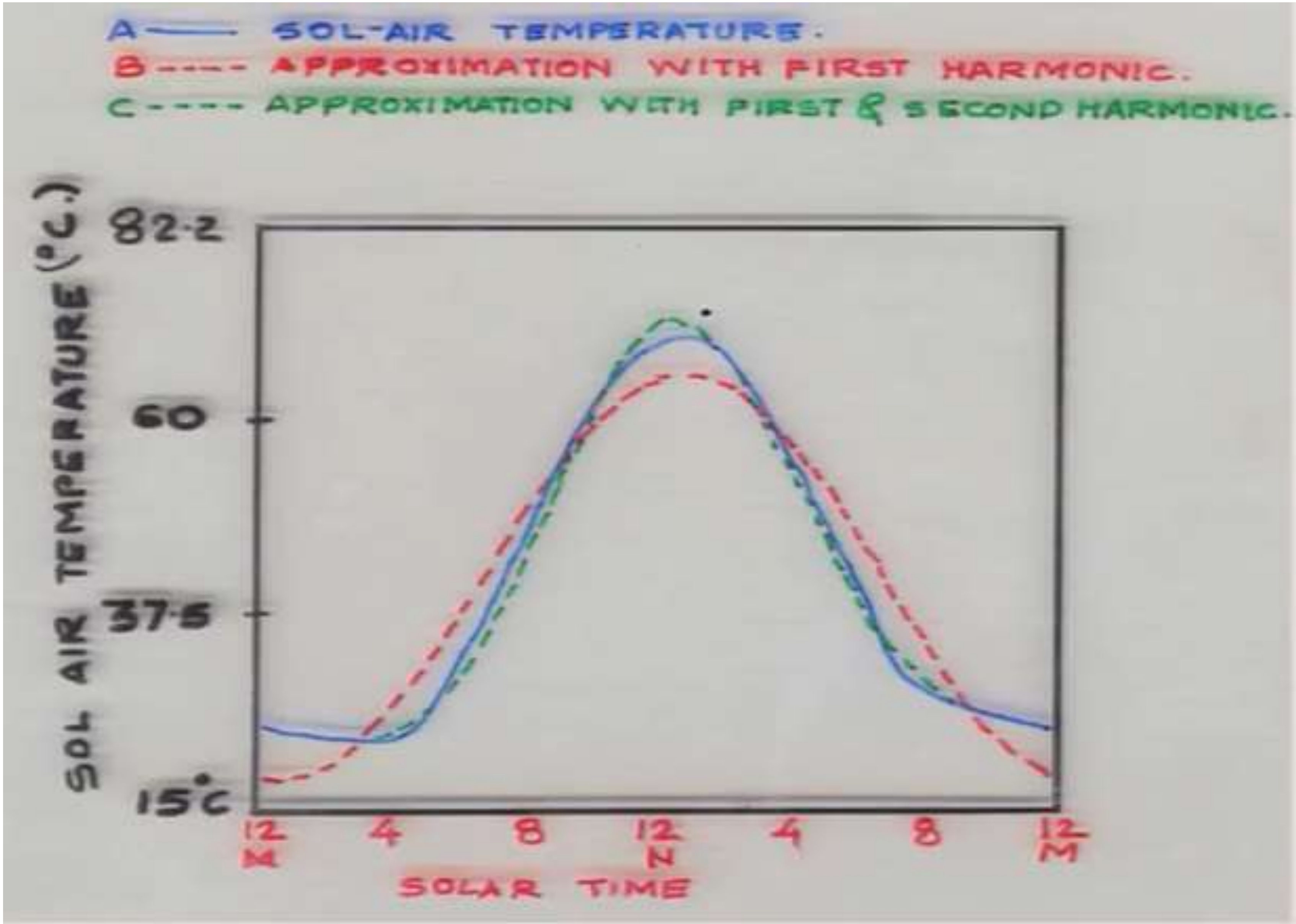
$$a_j = \frac{2}{p}\int_{-p/2}^{p/2} T(t)\ \cos\left(\frac{2\pi jt}{p}\right) dt$$

$$b_j = \frac{2}{p}\int_{-p/2}^{p/2} T(t)\ \sin\left(\frac{2\pi jt}{p}\right) dt$$

$$\bar{T} = \frac{1}{p}\int_{-p/2}^{p/2} T(t)\ dt$$

$$T_j = (a_j^2 + b_j^2)^{1/2}, \qquad \emptyset = \tan^{-1}\left(-\frac{b_j}{a_j}\right)$$

Daily Temperature Variation



Unsteady Heat Flow through wall

The steady flow deal by simple eq. $Q = UA\Delta T$

$$\frac{\partial T\,(x,t)}{\partial x} = -\frac{1}{k} q\,(x,t)$$

$q_{in} - q_{out}$ through unit area in 1-D situation is the rate at which heat is stored in 1x dx volume

$$\frac{\partial T\,(x,t)}{\partial x} = -\rho c \frac{\partial T}{\partial t}$$

Heat Transfer

Temp function of Time and space

$$\frac{\partial^2 T\,(x,t)}{\partial x^2} = \frac{\rho c}{k}\frac{\partial T(x,t)}{\partial t} = \frac{1}{\alpha}\frac{\partial \boldsymbol{T}(\boldsymbol{x},\boldsymbol{t})}{\partial t}$$

Diffusivity $\alpha = \frac{k}{\rho c}\mathrm{m^2/s}$

$\rho - Density\ ; c -$ specific heat (J/°C/kg)

Second order Differential equation

To solve this, many techniques, Numerical such as FDM, FE, FVM or Frequency domain solutions done with Laplace transformation…

Unsteady Heat Flow through wall

$$L\,[T(x,t)] = \int_0^\infty e^{-st}\,T(x,t)\,dt$$

LT is essentially converting Time domain in to domain of 's' variable

$$\frac{\partial^2 L\,[T(x,t)]}{\partial x^2} = \frac{s}{\alpha} L[T(x,t)] - T(x,0)$$

Putting initial condition at t=0, T(x,0)=0 & L[T(x,t)]= θ, the Ordinary differential equation in θ is

$$\frac{\partial^2 \theta}{\partial x^2} = \frac{s}{\alpha}\theta$$

Unsteady Heat Flow through wall

Solving the ODE, solution is obtained in θ & inverse transform gives the solution

Solving the auxiliary equation

$$D^2 = \frac{s}{\alpha}, \qquad D = \pm\sqrt{\frac{s}{\alpha}} = \pm p$$

$$\boldsymbol{\theta} = Ae^{-px} + Be^{px} \text{ (General solution)}$$

$$\frac{d\boldsymbol{\theta}}{dx} = -pAe^{-px} + pBe^{px}$$

For x=0, $\boldsymbol{\theta} = \boldsymbol{\theta_0}$, $\emptyset = \emptyset_0 = -\boldsymbol{k}\left(\frac{\boldsymbol{d\theta}}{\boldsymbol{dx}}\right)$ (*Defined*)

$$\theta_0 = A + B$$

$$\emptyset_0 = kpA - kpB$$

Unsteady Heat Flow through wall

$$\theta_0 = A + B \text{..........1}$$

$$\emptyset_0 = kpA - kpB \text{........2}$$

Solving above two equations…

$$A = \frac{1}{2}\left[\theta_0 + \frac{\emptyset_0}{kp}\right]$$

$$B = \frac{1}{2}\left[\theta_0 - \frac{\emptyset_0}{kp}\right]$$

Unsteady Heat Flow through wall

$\theta \ \& \ \emptyset \ can \ be \ rewritten \ in \ terms \ of \ \theta_0, \emptyset_0$

$$\theta = \frac{1}{2}\left[\theta_0 + \frac{\emptyset_0}{kp}\right]e^{-px} + \frac{1}{2}\left[\theta_0 - \frac{\emptyset_0}{kp}\right]e^{px}$$

$$\theta = \frac{1}{2}\theta_0[e^{-px} + e^{px}] + \frac{1}{2}\frac{\emptyset_0}{kp}[e^{-px} - e^{px}]$$

By replacing

$(e^{-px} + e^{px})/2$ = cosh-px&

$(e^{-px} - e^{px})/2$ = -2sinh-px

Unsteady Heat Flow through wall

$$\theta = \frac{1}{2}\theta_0[e^{-px} + e^{px}] + \frac{1}{2}\frac{\emptyset_0}{kp}[e^{-px} - e^{px}]$$

Replacing, p, & using hyperbolic functions

$$\theta(x,s) = \theta_0(0,s)cosh\sqrt{\frac{s}{\alpha}}x - \frac{\emptyset_0(0,s)}{kp}sinh\sqrt{\frac{s}{\alpha}}x$$

Unsteady Heat Flow through wall

Similarly for ∅

$$\emptyset = -k\left(\frac{d\theta}{dx}\right) = kpAe^{-px} + kpBe^{px}$$

$$\emptyset = kp\frac{1}{2}\left[\theta_0 + \frac{\emptyset_0}{kp}\right]e^{-px} - kp\frac{1}{2}\left[\theta_0 - \frac{\emptyset_0}{kp}\right]e^{px}$$

$$\emptyset = -\frac{1}{2}kp\theta_0[-e^{-px} + e^{px}] + \frac{1}{2}\emptyset_0[e^{-px} + e^{px}]$$

Using hyperbolic functions

$$\emptyset(x,s) = -\theta_0(0,s)k\sqrt{\frac{s}{\alpha}}sinh\sqrt{\frac{s}{\alpha}}x + \emptyset_0(0,s)cosh\sqrt{\frac{s}{\alpha}}x$$

Unsteady Heat Flow through wall

Rewriting the equations again, i.e. x replaced by l

Equations are based on initial BC i.e. at t=o T(temp)= 0

$$\theta(l,s) = \theta_0(0,s) cosh\sqrt{\frac{s}{\alpha}}l - \frac{\emptyset_0(0,s)}{kp} sinh\sqrt{\frac{s}{\alpha}}l$$

$$\emptyset(l,s) = -\theta_0(0,s)k\sqrt{\frac{s}{\alpha}} sinh\sqrt{\frac{s}{\alpha}}l + \emptyset_0(0,s) cosh\sqrt{\frac{s}{\alpha}}l$$

Unsteady Heat Flow through wall

In matrix form,

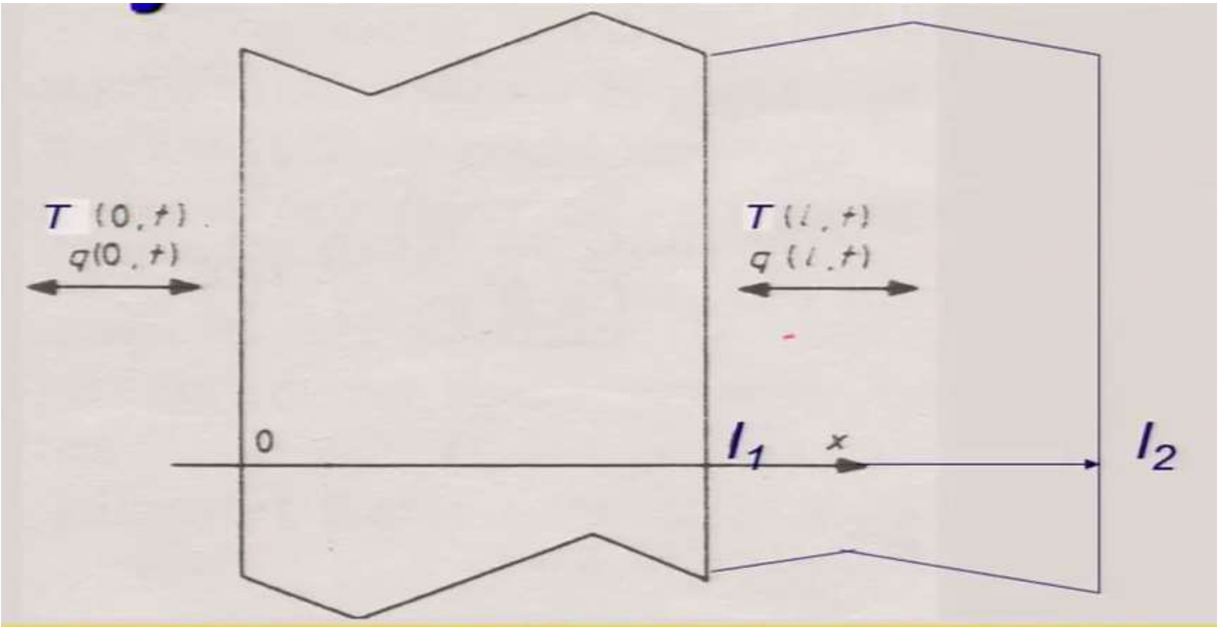
$$\begin{bmatrix} \theta(l,s) \\ \emptyset(l,s) \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} \theta(0,s) \\ \emptyset(0,s) \end{bmatrix}$$

$$m_{11} = m_{22} = \cosh \sqrt{\frac{s}{\alpha}} l \, ;$$

$$m_{12} = -\frac{1}{k\sqrt{\frac{s}{\alpha}}} \sinh \sqrt{\frac{s}{\alpha}} l$$

$$m_{21} = -k\sqrt{\frac{s}{\alpha}} \sinh \sqrt{\frac{s}{\alpha}} l$$

Unsteady Heat Flow through wall: Layered Construction



$$\begin{bmatrix}\theta(l_1,s)\\ \emptyset(l_1,s)\end{bmatrix} = \begin{bmatrix} m_{11}^1 & m_{12}^1 \\ m_{21}^1 & m_{22}^1\end{bmatrix}\begin{bmatrix}\theta(0,s)\\ \emptyset(0,s)\end{bmatrix}$$

$$\begin{bmatrix}\theta(l_2,s)\\ \emptyset(l_2,s)\end{bmatrix} = \begin{bmatrix} m_{11}^2 & m_{12}^2 \\ m_{21}^2 & m_{22}^2\end{bmatrix}\begin{bmatrix}\theta(l_1,s)\\ \emptyset(l_1,s)\end{bmatrix}$$

Unsteady Heat Flow through wall

$$\begin{bmatrix} \theta(l_2, s) \\ \emptyset(l_2, s) \end{bmatrix} = \begin{bmatrix} m_{11}^2 & m_{12}^2 \\ m_{21}^2 & m_{22}^2 \end{bmatrix} \begin{bmatrix} m_{11}^1 & m_{12}^1 \\ m_{21}^1 & m_{22}^1 \end{bmatrix} \begin{bmatrix} \theta(0, s) \\ \emptyset(0, s) \end{bmatrix}$$

$$\begin{bmatrix} \theta(L, s) \\ \emptyset(L, s) \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} \theta(0, s) \\ \emptyset(0, s) \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} m_{11}^2 & m_{12}^2 \\ m_{21}^2 & m_{22}^2 \end{bmatrix} \begin{bmatrix} m_{11}^1 & m_{12}^1 \\ m_{21}^1 & m_{22}^1 \end{bmatrix} \ldots\ldots$$

Unsteady Heat Transfer

For air layer ,

Thermal capacity of air layer is very small

Therefore, assume $\rho C \to 0, \& \frac{k}{\rho C} = \alpha \to \infty,$

That mean it will allow heat to go instantaneously,

$$l\sqrt{\frac{s}{\alpha}} \to 0$$

$$m_{11} = m_{22} = cosh\sqrt{\frac{s}{\alpha}}l \to 1$$

$$lim\sqrt{\frac{s}{\alpha}}l \to 0$$

Unsteady Heat Transfer

$$m_{12} = -\frac{1}{k\sqrt{\frac{s}{\alpha}}} sinh\sqrt{\frac{s}{\alpha}}l = \frac{l}{k} - \frac{sinh\sqrt{\frac{s}{\alpha}}l}{\sqrt{\frac{s}{\alpha}}l} = -\frac{l}{k} = -1/h$$

$$Lim\sqrt{\frac{s}{\alpha}}l \to 0 \; lim\sqrt{\frac{s}{\alpha}}l \to 0$$

For Air Layer

$$\begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{h} \\ 0 & 1 \end{bmatrix}$$

Unsteady Heat Flow through wall

To simplify again,

When, s=iω is used in Laplace transform & using lower limit of integration as -∞ ; for 1^{st} harmonic.

- All temperature and heat fluxes are multiplied by $e^{-i\omega 1t}$ & integrated from -∞ to +∞ to obtain the transform

$$\int_0^{\infty} e^{-i\omega_1 t} T(t) dt = \int_{-\infty}^{\infty} T(t)\, cos(\omega_1 t)\, dt - i \int_{-\infty}^{\infty} T(t)\, sin(\omega_1 t)\, dt$$

$$=\pi(a_1 - ib_1)$$

a_1 and b_1 is Fourier's coefficient

Unsteady Heat Transfer

$$\pi(a_1 - ib_1) = \pi T_o e^{-i\omega_1 t}$$

$$T_o = \sqrt{(a_1^2 + b_1^2)}$$

$$\omega_1 = \tan^{-1}(-b_1/a_1)$$

❖ T(t), q(t) thus gets transformed to Fourier amplitude for the corresponding harmonic multiplied by $\pi e^{-i\omega_1 t}$

Transmission Matrix

All temperature & heat fluxes are multiplied by exponent $\pi e^{-i\omega,t}$; $\pi e^{-i\omega,t}$ can be ignored but respective ω, need to be used in the transmission matrix.

$$\begin{bmatrix} T_L \\ q_L \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \begin{bmatrix} T_o \\ q_o \end{bmatrix}$$

$$m_{11} = m_{22} = cosh \sqrt{\frac{i\omega}{\alpha}}\, l;$$

$$m_{12} = - \frac{1}{k\sqrt{\frac{i\omega}{\alpha}}}\ sinh \sqrt{\frac{i\omega}{\alpha}}\, l$$

$$m_{21} = - k\sqrt{\frac{i\omega}{\alpha}}\ sinh \sqrt{\frac{i\omega}{\alpha}}\, l$$

Transmission Matrix

$$i^{1/2}(w/\alpha)^{1/2} = (2i)^{1/2}(w/2\alpha)^{1/2}$$

$$(2i)^{1/2} = [(1+i)^2]^{1/2} = 1+i$$

$$F = (w/2\alpha)^{1/2}$$

$$m_{11} = \cosh(Fl + iFl)$$

$$m_{12} = -\sinh(Fl + iFl)/(kF + ikF)$$

$$m_{21} = (-kF + ikF)\sinh(Fl + iFl)$$

$$m_{22} = \cosh(Fl + iFl)$$

Transmission Matrix

$$\begin{bmatrix} T\ (l) \\ q\ (l) \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} T\ (0) \\ q\ (0) \end{bmatrix}$$

OR

$$\begin{bmatrix} T_i \\ q_i \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} T_o \\ q_o \end{bmatrix}$$

Frequency Domain Response factors

Admittance factor (Ỹ):

This is defined as the **amount of energy entering a surface for each degree of temperature swing** at the environmental point.

It is used to represent enclosure response to give the equivalent swing in temperature about some mean value due to a cyclic load on an enclosure.

Consequently mathematically defined as,

$$\tilde{Y}(l,t)=\frac{q\,(l,t)}{T(0,t)}=\frac{qi}{Ti}$$ = heat flux/swing of inside temperature

qi will be find by decrement factor and utilised here to find the internal room temperature

Admittance response factor

Ỹ can be determined from transmission matrix, assuming constant outside temperature, i.e. $\check{T}_o=0$

$$\begin{bmatrix} Ti \\ qi \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} To \\ qo \end{bmatrix}$$

For $\check{T}_o$ =0

Ti = Bq_o

qi= Dq_o

$$\tilde{Y} = \frac{qi}{Ti} = \frac{D}{B}$$

Frequency Domain response Factor

To simplify again,

Decrement response factor (μ):

This is defined as the ratio of the cyclic flux transmission to the steady state flux transmission. (Or temperature)

It is applied to fluctuations (about mean) in external temperature or flux harmonics impinging on exposed opaque surfaces undergoing transient heat transfer.

Consequently mathematically defined as,

$\tilde{U}=\frac{q\,(l,t)}{T(0,t)}=\frac{qi}{To}$ **= heat flux/swing of outside temperature**

$$\mu=\frac{\tilde{U}}{U}$$

Decrement response factor

μ can be determined from Transmission matrix assuming constant inside temperature i.e. $\check{T}_i = 0$

$$\begin{bmatrix} Ti \\ qi \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} To \\ qo \end{bmatrix}$$

$$\begin{bmatrix} To \\ qo \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1} \begin{bmatrix} Ti \\ qi \end{bmatrix}$$

$$\begin{bmatrix} To \\ qo \end{bmatrix} = \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \begin{bmatrix} Ti \\ qi \end{bmatrix}$$

For $\check{T}_i = 0$ To = $-Bq_i$

$$\tilde{U} = \frac{qi}{To} = \frac{1}{-B} \qquad \mu = \frac{1}{U\,(-B)}$$

Decrement Factor

M′ = inv(M)

1/-B = 1/M′ (1,2);

U= (1/(1/ho+l/k+1/hi))

(Complex decrement) Cdec = 1/-BU

μ = abs(cdec)

$\phi = \text{angle (cdec/U)}\pi*12$

1/-BU =X+iY

μ = $\sqrt{X^2 + Y^2}$

Tan(ϕ) $= \text{Y/X}$

Ventilation Heat Exchange (Q_{cv})

Outside air coming In= Inside air going out

If air flow = V m^3/sec

i.e. volume exchange in unit time (sec) = V m^3

C_p – Specific heat of air at constant pressure

P= Density of air

$Q_{cv} = \rho V C_p (T_{oa} - T_{ia})$

ρC_p – Volumetric heat capacity = 1300 Joules/K. m^3

V_R= Volume of room

N = Number of air change per hr.

$Q_{cv} = 1300/3600\ N\ V_R\ (T_{oa} - T_{ia}) = 1/3\ N\ V_R\ (T_{oa} - T_{ia})$

Radiation Heat Exchange (Q_R)

$Q_R = \sum I\ AW\theta$

Where,

I= Intensity of radiation (W/m^2)

θ – Solar Gain factor= 1 for open windows

A_W- Area of Window

Casual Heat Gain (Q_{cs})

$$Qcs = \sum miQi$$

Mean Temperature in the space

$$\bar{Q}_{cd} = \sum U_j A_j (T_{oe} - T_{ia}) = \sum U_j A_j (T_{oa} + (\alpha I / h_o)_j - T_{ia})$$

Toe- Equivalent sol air temperature

$$\bar{Q}_{cd} = \sum U_j A_j (T_{oa} - T_{ia}) + \sum U_j A_j (\alpha I / h_o)_j$$

For steady state mean temperature

$$\bar{Q}_{cd} + \bar{Q}_R + \bar{Q}_{cv} + \bar{Q}_{cs} = 0$$

If inside & out side mean temperature constant.

Q_R and Q_{cs}- Heat gain

Q_{cd} & Q_{cv}- Heat loss

Mean Temperature in the space

$$\sum U_j A_j (\overline{T}_{oa} - \overline{T}_{ia}) + \sum U_j A_j (\alpha\,\bar{\imath} / h_o)_j + \sum A\bar{\imath}\,\theta + \overline{C}_V (\overline{T}_{oa} - \overline{T}_{ia}) + \overline{Q}_{cs} = 0$$

$$\sum U_j A_j (\overline{T}_{oa} - \overline{T}_{ia}) + \overline{C}_V (\overline{T}_{oa} - \overline{T}_{ia}) + \overline{Q} = 0$$

$$(\overline{T}_{oa} - \overline{T}_{ia}) = -\overline{Q} / (\sum U_j A_j + \overline{C}_V)$$

$$\overline{T}_{ia} = \overline{T}_{oa} + \{\overline{Q} / (\sum U_j A_j + \overline{C}_V)\}$$

Where,

$$\overline{Q} = \sum U_j A_j (\alpha\,\bar{\imath} / h_o)_j + \sum A\bar{\imath}\,\theta + \overline{Q}_{cs}$$

Mean Temperature in the space

A room 6 m x 5 m x 3m (ht) with one external wall on the long axis has a single glazed window 4.5 m x 2 m facing south. Calculate the mean internal temperature given that T_{oa} = 17° C and the mean global irradiance on exposed wall is 180 W/m^2 . Assume α of solid wall = 0.4 and h_o 9 W/m^2.

U_{wall} = 0.7. $U\text{-}_{window}$= 5.6.

Assume two air changes per hour for the room and all adjacent room to be the same temperature. Solar gain factor for glass = 0.76.

Mean Temperature in the space

$V_R = 6 \times 5x3 = 90m^2$

A window= $4.5 \times 2 = 9\ m^2$

A wall = $6x\ 3 - 9 = 9\ m^2$

$I = 180\ W/m^2$

Mean heat gain through wall = UA (α I/ho)

$= 0.7x\ 9 \times 0.4\ x180/9 = 50.4\ W$

Mean heat gain through window= AIθ

$= 9 \times 180x\ 0.76 = 1231.2\ W$

Mean Temperature in the space

$$\mathbf{Cv = \frac{1}{3} NV_R = \frac{1}{3} * 2 \; * 90 = 60 \; W/°C}$$

U_jA_j = 0.7*9+ 5.6*9 = 56.7

$$\overline{T}_{ia} = \overline{T}_{oa} + \{\overline{Q}/(\sum U_j A_j + \overline{C}_V)\}$$

T_{ia} = 17 + {1281.6/(60+56.7) }

= 17+ {1281/116.7 }

= 27.9°C

Inside Temperature

$$\boldsymbol{Recall, Mean\ Room\ temperature}$$

$$\check{T}\boldsymbol{i} = \check{T}\boldsymbol{o} + \frac{\bar{Q}_{\boldsymbol{T}}}{(\sum \boldsymbol{AU} + \boldsymbol{Cv})}$$

$\bar{Q}_{T}$ = $\overline{\boldsymbol{Q}}_{\boldsymbol{R}} + \overline{\boldsymbol{Q}}_{\boldsymbol{cs}}$

$\boldsymbol{Room\ temperature\ at\ any\ instant\ t\ is}$:

T_i(t) = $\check{T}\boldsymbol{i} + \check{T}\boldsymbol{i}\ (t)$ (Fluctuating component)

$\check{T}\boldsymbol{i}\ (t)$ **swing needs to be obtained**

Fluctuating Heat gains

The total fluctuating energy gain at the environmental point and due to any particular excitation frequency is given by:

$$\tilde{Q}_T(t) = \tilde{Q}_{fs}(t) + \tilde{Q}_S(t) + \tilde{Q}_c(t) + \tilde{Q}_{fc}(t) + \tilde{Q}_v(t)$$

Where,

$\tilde{Q}_{fs}(t)$**- Solar radiation on Opaque body fluctuating heat gain**

$\tilde{Q}_S(t)$**- Transparent surface solar fluctuating heat gain**

$\tilde{Q}_c(t)$**- Casual gain fluctuating heat**

$\tilde{Q}_{fc}(t)$**- Opaque surface fluctuating heat gain**

$\tilde{Q}_{gc}(t)$**- Transparent surface conduction fluctuating heat gain**

$\tilde{Q}_v(t)$**- Fluctuating ventilation heat transfer**

Fluctuating Heat gains

Solar radiation on Opaque body fluctuating heat gain $\tilde{Q}_{fs}(t) =$

$$\tilde{Q}_{fs}(t) = \sum_{i=1}^{N}[A_i U_i R_o \mu_i \alpha_i \tilde{I}_{so}(t - \emptyset_d)]$$

Opaque surface fluctuating heat gain $\tilde{Q}_{fc}(t) =$

$$\tilde{Q}_{fc}(t) = \sum_{i=1}^{O}[A_i U_i \mu_i \tilde{T}_o(t - \emptyset_d)]$$

Where,

μ - $\frac{\tilde{U}}{U}$ **=Decrement response factor**

Ro= 1/ho= **surface heat transfer resistance coefficient**

$\emptyset_d$ **is decrement time lag**

$$\tilde{I}_{so}(t - \emptyset_d) = I_{so}(t - \emptyset_d) - \bar{I}_{so}$$

Fluctuating Heat gains and Internal temperature

Fluctuating heat gain through surfaces and gain of air is equal to fluctuating heat input over mean

$$\widetilde{T}_i(t)\left(\sum AY + C_v\right) = \widetilde{Q}_T(t - \phi_a)$$

$$\widetilde{T}_i(t) = \frac{\widetilde{Q}_T(t - \phi_a)}{(\sum AY + C_v)}$$

Where, Y is admittance factor

ϕ_a= time lag

Thermal Admittance

- Thermal performance of the wall/roofs can be measured by two parameters: thermal insulation and thermal mass.
- Thermal transmittance is a steady-state property and it is the measure of thermal insulation
- Thermal admittance (w/mk) is the measure of thermal mass. An ability to absorb the heat from and release it to a space over time.
- Amount of energy leaving the internal surface of the element into the room per unit degree of temperature swing

Thermal Admittance

- This can be used for thermal storage capacity of a materials absorbing heat from and releasing it to a space through cyclic temperature variations and thus evening out temperature variations and so reducing the building services system.

- This is a measure of the ability of a surface to smooth out temperature variations in a space and represents the rate of energy entry into a structure rather than that of passage through it.

For reduced cooling loads, thermal transmittance should be as low as possible and thermal admittance should be as high as possible.

Thermal transmittance

- **Thermal transmission through unit area of a building unit divided by the temperature difference between the air or other fluid on either side of the building unit in steady state conditions is termed as Thermal Transmittance (*U-value*).**

Overall U- factor of typical wall assembly construction:

$$U = 1/\left(1/h_i + \sum_{i=1}^{n} L_i/K_i + 1/h_o\right) \quad \text{........(i)}$$

Where, h_o (19.90 W/(m² K) and h_i (9.3 W/(m² K) are the outside and inside film heat transfer coefficients, L_i and K_i are thicknesses and thermal conductivities of material layers.

•A measure of the overall ability of a building element (wall / window / floor / roof) to prevent heat loss (W/m²K).

It includes: Material resistances, surface resistances & air space resistances

Energy Conservation Building Code

The provisions of this code apply to:

(a) Building envelope

(b) Thermal comfort systems and controls (only those installed by developer/ owner)

(c) Lighting systems and controls (only those installed by developer/ owner)

(d) Electrical systems (installed by developer/ owner)

(e) Renewable energy systems

ECBC 2017 Requirements

Table 4.7 Opaque Assembly Maximum U-factor (W/m2) Requirements for a ECBC compliant building

	Composite	Hot and dry	Warm and humid	Temperate	Cold
All building types, except below	0.40	0.40	0.40	0.55	0.34
No Star Hotel < 10,000AGA	0.63	0.63	0.63	0.63	0.40
Business <10,000AGA	0.63	0.63	0.63	0.63	0.40
School <10,000AGA	0.85	0.85	0.85	1.00	0.40

Table 4.8 Opaque Assembly Maximum U-factor (W/m2) Requirements for a ECBC + compliant building

	Composite	Hot and dry	Warm and humid	Temperate	Cold
All building types, except below	0.34	0.34	0.34	0.55	0.22
No Star Hotel < 10,000AGA	0.44	0.44	0.44	0.44	0.34
Business <10,000AGA	0.44	0.44	0.44	0.55	0.34
School <10,000AGA	0.63	0.63	0.63	0.75	0.44

Table 4.7 Opaque Assembly Maximum U-factor (W/m2) Requirements for Super ECBC building

	Composite	Hot and dry	Warm and humid	Temperate	Cold
All building types	0.22	0.22	0.22	0.22	0.22

Energy Conservation Building Code (Code) is to provide minimum requirements for the energy-efficient design and construction of buildings

Roof Assembly Max. *U- factor* Requirements

The Roof Insulation shall be applied externally as part of the Structural Slab and not as part of the False Ceiling

Table 4.4 Roof Assembly U-factor (W/m2) Requirements for ECBC Compliant building

	Composite	Hot and dry	Warm and humid	Temperate	Cold
All building types, except below	0.33	0.33	0.33	0.33	0.28
School <10,000AGA	0.47	0.47	0.47	0.47	0.33
Hospitality > 10,000AGA	0.20	0.20	0.20	0.20	0.20

Table 4.5 Roof Assembly U-factor (W/m2) Requirements for ECBC + Compliant building

	Composite	Hot and dry	Warm and humid	Temperate	Cold
Hospitality, Healthcare Assembly	0.20	0.20	0.20	0.20	0.20
Business Educational Shopping Complex	0.26	0.26	0.26	0.26	0.20

Table 4.6 Roof Assembly U-factor (W/m2) Requirements Super ECBC building

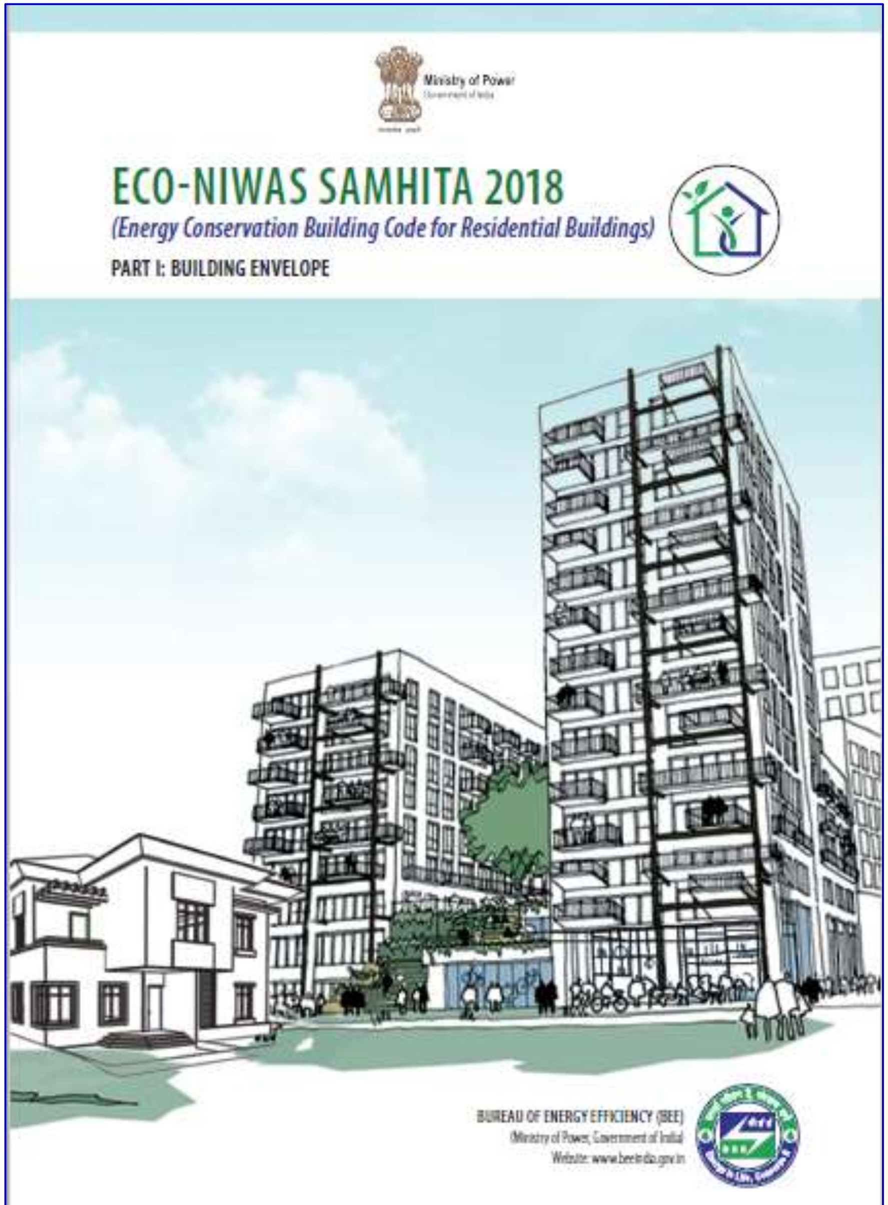
	Composite	Hot and dry	Warm and humid	Temperate	Cold
All Building types	0.20	0.20	0.20	0.20	0.20

Thermal Transmittance for Different Roofing Systems

Building Sections / Components	U-value (W/m^2K)
R.C. Plank and joist roofing system 60 mm RC plank + 50 mm mud phuska + 50 mm brick tiles + 15 mm cement plaster	2.71
100 mm thick R.B.C slab + 50 mm mud phuska + 50mm brick tiles + 15 mm cement plaster	2.36
Brick panel roofing system: Panel size 1150 x 530 x 76 mm + R.C.C Joist	2.16
115 mm RCC + 75mm Mud Phuska + 50 mm brick tile	2.01

None of the Roofing Assemblies fulfill the ECBC Criteria

Energy Conservation Building Code



CONTENTS

Energy Conservation Building Code – Residential 2018

- Code sets minimum performance standards for building envelope to limit heat gains (for cooling dominated climates) and limit heat loss (for heating dominated climates) through it.

- RETV is the **net heat gain rate** (over the cooling period) through the **building envelope of dwelling units** (excluding roof) divided by the area of the building envelope (excluding roof) of dwelling units. Its unit is W/m^2

$$RETV = \frac{1}{A_{envelope}} \times \left[\begin{array}{l} \left\{ a \times \sum_{i=1}^{n} \left(A_{opaque_i} \times U_{opaque_i} \times \omega_i \right) \right\} \\ + \left\{ b \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times U_{non-opaque_i} \times \omega_i \right) \right\} \\ + \left\{ c \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times SHGC_{eq_i} \times \omega_i \right) \right\} \end{array} \right]$$

Residential Envelope Transmittance Value (RETV) for building envelope (except roof) shall comply with the maximum RETV of 15 W/m^2

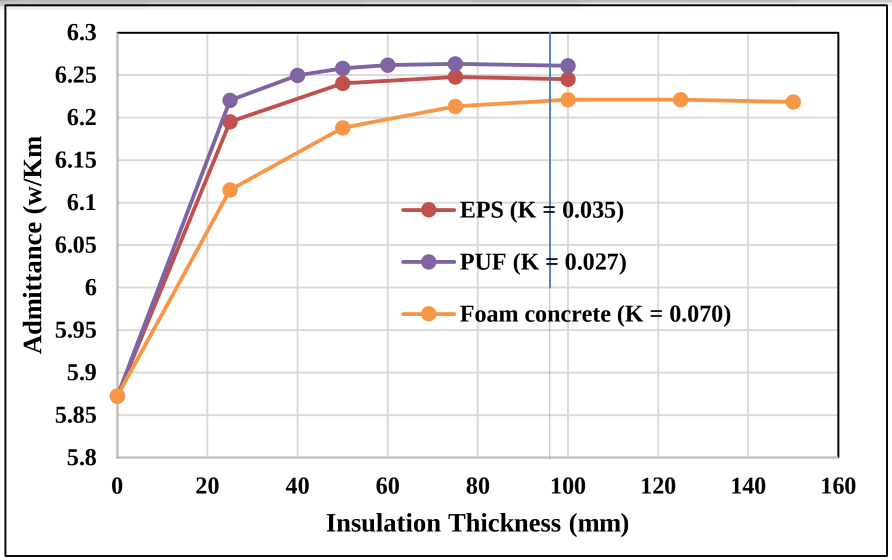
- **Thermal transmittance of the building envelope (except roof) for cold climate shall comply with the maximum of 1.8 W/m^2.K.**

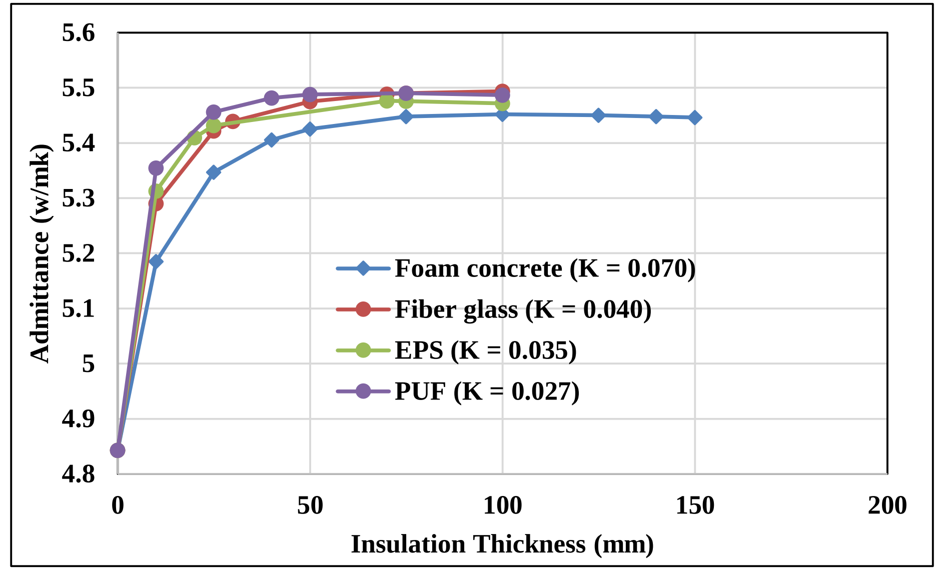
- **Thermal transmittance of roof shall comply with the maximum *U_{Roof}* value of 1.2 W/m^{2}K**

Table 3 Coefficients (a, b and c) for RETV formula

Climate zone	a	b	c
Composite	6.06	1.85	68.99
Hot-Dry	6.06	1.85	68.99
Warm-Humid	5.15	1.31	65.21
Temperate	3.38	3.37	63.69
Cold	Not applicable (Refer Section 3.5)		

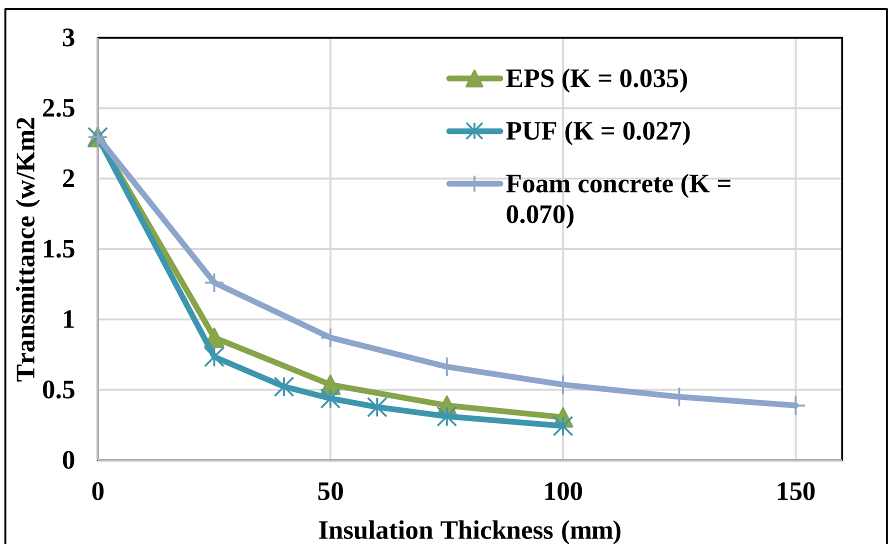
Thermal Admittance & Transmittance

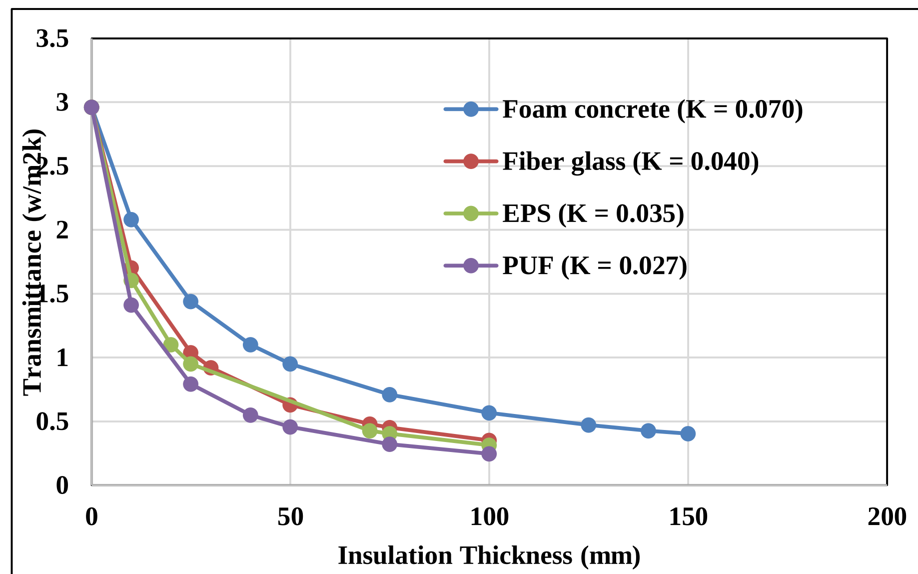




Roof

Wall





CLIMATOLOGY : Thermal Comfort

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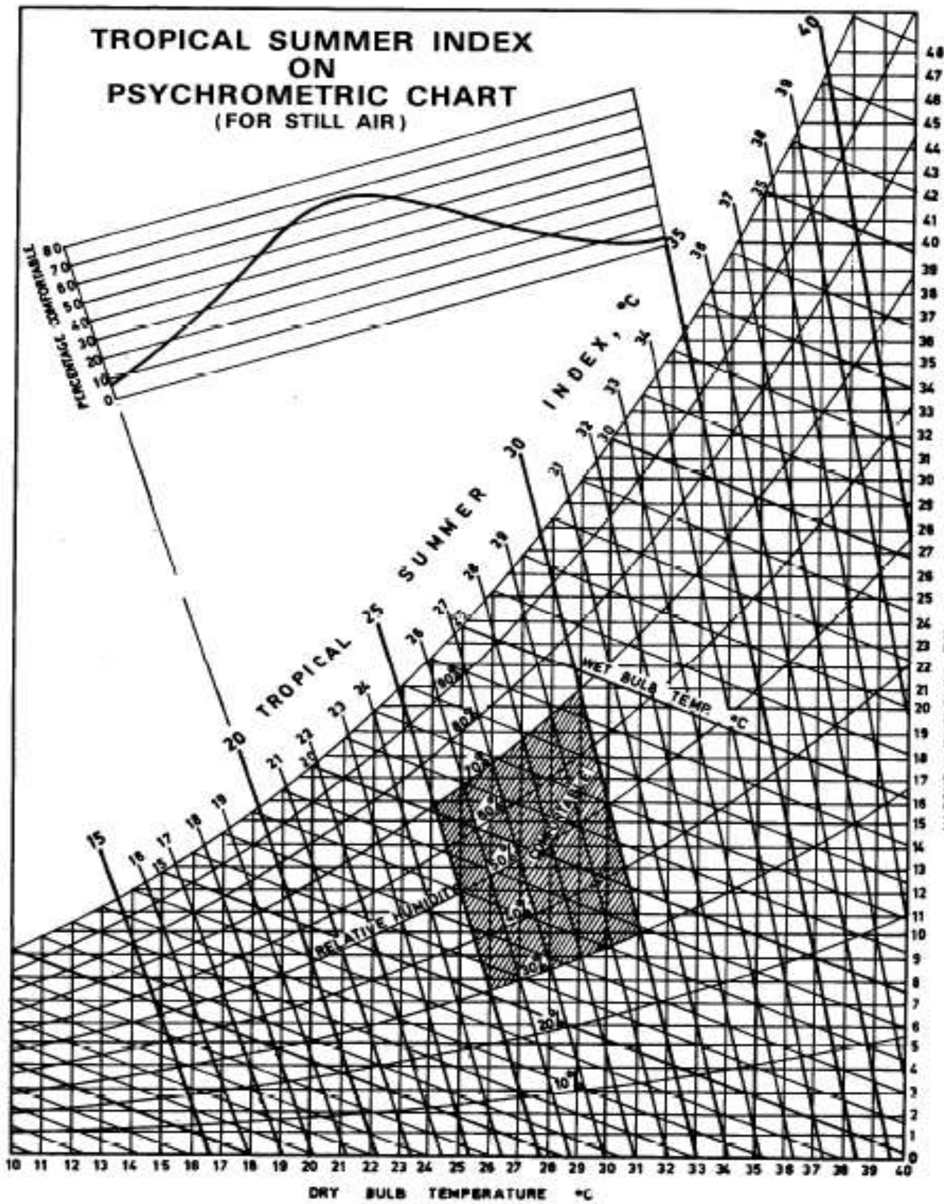

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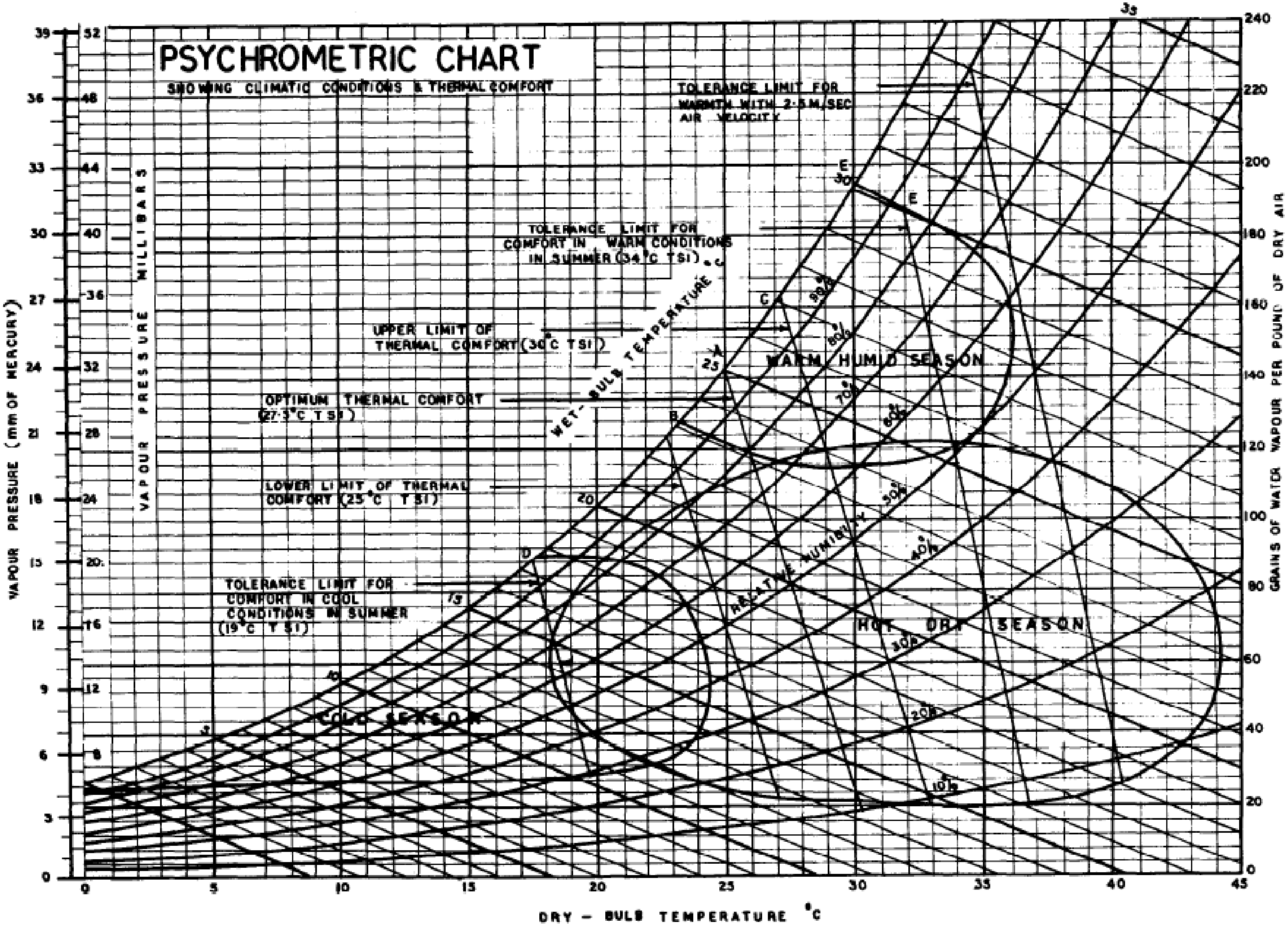

FIG. 3 PSYCHROMETRIC CHART (SHOWING CLIMATIC CONDITIONS AND THERMAL COMFORT)

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